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ABUNDANCE AND DISTRIBUTION OF EGGS AND LARVAE AND SURVIVAL OF LARVAE OF JACK MACKEREL (*TRACHURUS SYMMETRICUS*)

By DAVID A. FARRIS

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ABSTRACT

Distribution and abundance of eggs and larvae of the jack mackerel, *Trachurus symmetricus* (Ayres), and survival of the larvae are described, utilizing quantitative data collected on monthly cruises of the California Cooperative Oceanic Fisheries Investigations during 1951–54.

Spawning in the period 1951–1954 occurred from Washington to Magdalena Bay, Baja California. In each of the 4 years it began in February and ceased by October. The peak month of spawning was March in 1951 and May in 1952, 1953, and 1954. About 30 percent of the spawning occurred during the peak month. Estimates of egg abundance varied by less than a factor of 2 during the 4 years studied.

The effect of temperature on the rate of development of eggs was investigated. Regression statistics are given for the developmental rate. Reliability of the regression was checked by direct observation of developing eggs at controlled temperatures.

The annual estimates of survival for 1952, 1953, and 1954 indicate a reasonably constant survival of month-old jack mackerel larvae in these years.

The growth rate of jack mackerel larvae was approximated from data derived by direct observation of developing jack mackerel larvae under laboratory conditions and was described by two successive logarithmic growth curves. The second curve originates at yolk sac absorption and has the lesser slope.

Survival data may be broken into two periods: the first period, concurrent with the fast growth period, is characterized by poor survival and may be the critical period; in the second, survival is much better and growth much slower.

ABUNDANCE AND DISTRIBUTION OF EGGS AND LARVAE AND SURVIVAL OF LARVAE OF JACK MACKEREL (*TRACHURUS SYMMETRICUS*)

By DAVID A. FARRIS, *Fishery Research Biologist*
BUREAU OF COMMERCIAL FISHERIES

The purposes of this study are to delimit both atially and temporally the spawning of the ck mackerel, *Trachurus symmetricus* (Ayres) 85, and to estimate the abundance of the gs and the survival rate of the larvae. Quan- ative data collected on monthly cruises of the lifornia Cooperative Oceanic Fisheries Investi- tions, 1951 through 1954, are utilized in the udy.

Data derived from the study of eggs and larvae ay give insight into the present abundance and ture fluctuations of the adult population, and timates of larval mortality may aid in predict- g future recruitment to the fishery. With nowledge of the fecundity, estimates of egg undance may be used to ascertain the present ze of the adult population. These data may so be compared with physical, chemical, and her biological data gathered by the California operative Oceanic Fisheries Investigations.

To accomplish the stated purposes of this study, e following information was needed:

1. Boundaries of the area occupied by devel- ing eggs and larvae.
2. Seasonal distribution of the eggs and larvae thin those boundaries.
3. Quantitative depth distribution of the eggs d larvae.
4. Relation between temperature and rate of velopment of eggs and larvae.

The author appreciates the help and encouragement given him by E. H. Ahlstrom, D. E. ohlschlag, and John C. Marr during the course this study; the assistance of O. E. Sette in the eparation of the manuscript; and the valuable vice of Bruce Taft in the preparation of the atistical portion of this paper. George Mattson epared most of the figures. Also, without the help of members of the California Marine Research Committee and its cooperating agencies and the staff of the South Pacific Fishery Investigations[1] this study could not have been undertaken. The laborious proofreading was done by Mrs. Paula K. Farris.

REVIEW OF THE FISHERY

The carangids most commonly found in the area surveyed by the California Cooperative Oceanic Fisheries Investigations are listed by Barnhart (1936) and Fowler (1944). The family is largely tropical or subtropical in its distribution, *Trachurus symmetricus* being a notable exception. Only three members of the family are taken in any numbers by the California Cooperative Oceanic Fisheries Investigations: yellowtail, *Seriola dorsalis* Gill; Mexican scad, *Decapterus hypodus* Gill; and jack mackerel, *Trachurus symmetricus* (Ayres). The larvae of all three species are known, so that identification is possible. The yellowtail and jack mackerel are the only carangids of any economic importance in the area (Clothier and Greenhood, 1956).

Well over 80 percent of the jack mackerel fishery is located in waters off southern California (i.e., from Point Conception to the Mexican border). In some years 99 percent of the catch is made in this region. Less than 1 percent of the total catch is taken in waters as far north as Eureka, California (i.e., Point Conception to Eureka).

Before 1947 the jack mackerel catch never exceeded 7,550 tons (Roedel, 1949: p. 31–32), and since then it has not fallen below that figure. During 3 years, 1947, 1950, and 1952, the catch exceeded 62,500 tons. The fluctuations of the jack mackerel catch more or less complement fluctuations in the sardine catch (Clothier and Greenhood,

NOTE.—The author's official address is San Diego State College, San Diego, lifornia.
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[1] Presently the Bureau of Commercial Fisheries Biological Laboratory, La Jolla, Calif.

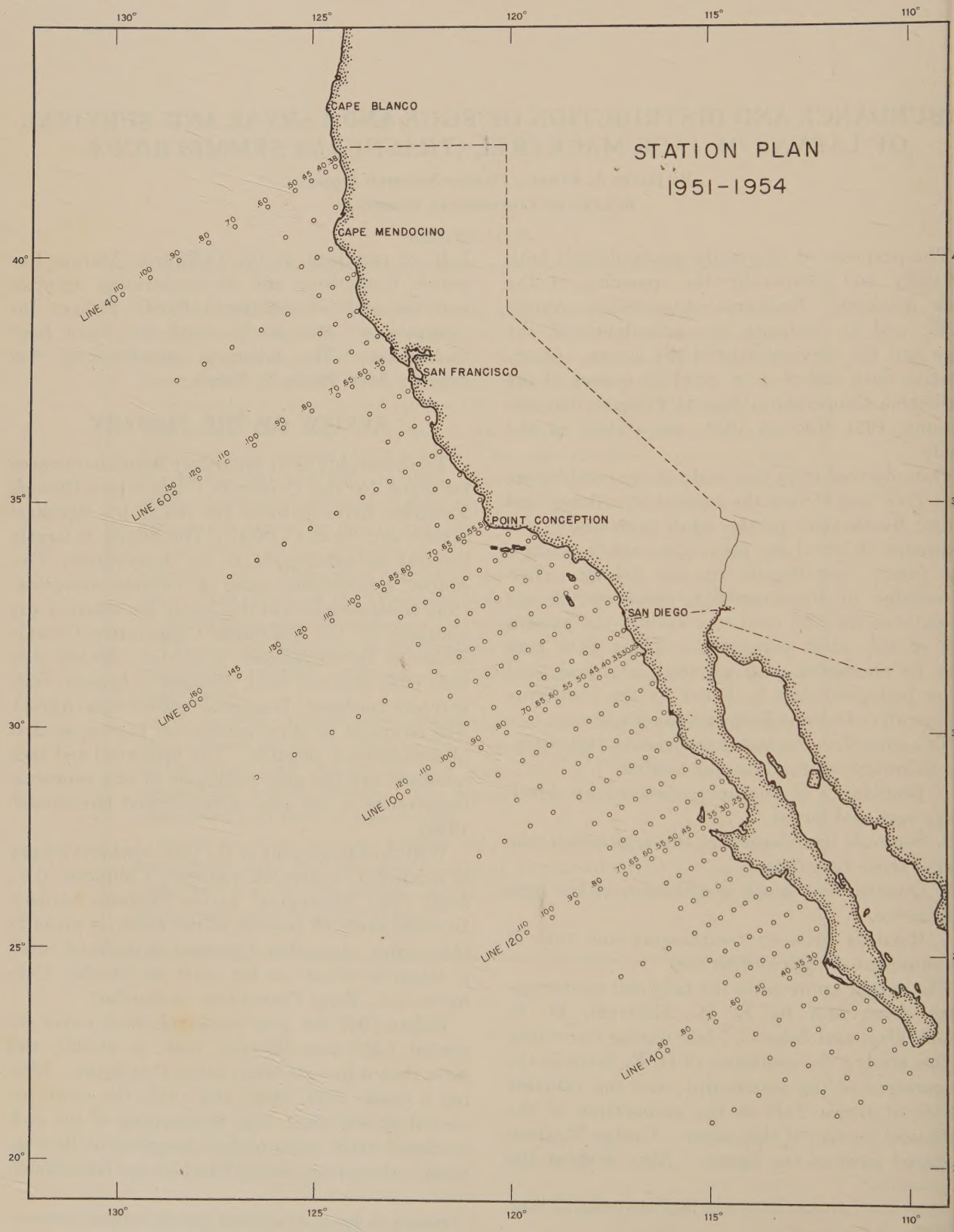


FIGURE 1.—Chart of stations occupied by the California Cooperative Oceanic Fisheries Investigations 1951–1954.

956: p. 8 and 12). The catch fluctuations since 947 arise primarily from three causes: (1) Availbility of sardines and Pacific mackerel, (2) fluctuations in demand for canned jack mackerel, and 3) availability of the jack mackerel. Since jack nackerel are packed as "substitute sardines," atch data do not necessarily reflect the size of the dult population. Eventual independence of the ndustry is assured, however, by the world's inreasing need for cheap protein and by technoogical advances in the packing of this species.

Jack mackerel are taken with a variety of gear; owever, more than 99 percent are taken with urse seines and lampara nets. The operation of is gear is described by Scofield (1951). Some ack mackerel are taken by sport fishermen using ve bait. In 1953, the sport catch was unusually rge, nearly 200,000 fish being taken (Fitch, 1956: . 27). However, this catch amounts to less than percent of the commercial catch.

Except for a minor amount used in the fresh-fish arket, the commercial catch is used for canning. ack mackerel are principally packed sardine style, sually in tall, 1 pound cans. A small part of the atch is packed in other ways.

To date, the catch of jack mackerel has not unergone any sustained decline. Therefore, all the reviously mentioned data take on an added signifance when one considers that many fishery inestigations are initiated after the industry has xperienced a decline in the number of catchable sh (Walford, 1948). By noting the variations in ie strength of spawning, stock size, mortality, cetera, now while fishing mortality is relatively w, future observations under conditions of higher shing mortality should permit the assessment of ie effects of man on the population size of the jack ackerel.

METHODS OF COLLECTING DATA

Since this study of jack mackerel constitutes but rt of a larger and more comprehensive study of ie ecology of pelagic fishes off the coast of Calirnia, the methods used are those originated by ie Bureau of Commercial Fisheries Biological aboratory at La Jolla and adopted by the staffs the California Cooperative Oceanic Fisheries nvestigations. These methods have been planned maximize the amount of information obtainable om this ecological province.

The methods used in collecting and processing these data, with a summary of the previous year's work are found in reports of the California Marine Research Committee, the sponsoring organization of the California Cooperative Oceanic Fisheries Investigations, for 1950, 1952, 1953, 1955, and 1956. More detailed explanations are given by Ahlstrom (1948 and 1953), and in the following discussion.

The station pattern and numbering system are described in Station Positions of the California Cooperative Sardine Research Program, prepared by the Scripps Institution of Oceanography and the U.S. Fish and Wildlife Service (1952). The stations laid out in lines occupied during the period 1951–54 are shown in figure 1. The exact location of each station (at each occupancy) during 1951–54 is given by Staff, South Pacific Fishery Investigations (1952, 1953, 1954, and 1955). A plankton-net tow (Ahlstrom, 1953), Nansen bottle cast, and bathythermograph cast are made at each station. Temperature data are obtained from the reversing thermometers on Nansen bottles and from bathythermograms. The obliquely hauled plankton net is retrieved from a depth of approximately 140 meters (200 meters of wire out) at an average rate of 20 meters of wire per minute. The angle from the vertical of the towing wire is kept as close as possible to 45 degrees. A current meter placed in the mouth of the net measures the volume of water strained. The sample obtained is preserved in its entirety in a buffered formalin solution, and these preserved samples are subsequently examined for fish eggs and larvae. The numbers of jack mackerel larvae and localities in which they were taken during 1952–54 are given in Ahlstrom (1954a) and Ahlstrom and Kramer (1955, 1956). The numbers of jack mackerel eggs and localities in which they were taken in 1951–54 are given by Farris (1958).

ESTIMATING EGG ABUNDANCE

The method used to estimate egg abundance has been described in detail by Sette and Ahlstrom (1948) and Ahlstrom (1954b). The monthly estimates of egg abundance are obtained from the relation—

$$C_M = \sum_{i=1}^{n} c_i w_i t_i$$

where

C_M = the monthly estimate of egg abundance

n=the number of stations considered
c_i=the average number of eggs spawned per day at the ith station[2]
w_i=the weighting factor for space in standard area (i.e., units of 10 m^2 of sea surface)
t_i=the time factor which is equal to one-half the time from the preceding occupancy of the station plus one-half the time to the succeeding occupancy.

An annual estimate of abundance is obtained by summing the monthly estimates for the entire year.

The eggs are identified and the number belonging to each species is recorded by station. The count for each station is adjusted so that all results are expressed as the number of eggs under a standard area which is 10 square meters of sea surface (Ahlstrom, 1953). This standardized haul value (c'_i) is the product of the raw count times a standard haul factor, which is derived for each haul by dividing 10 by the average volume of water strained per meter of depth for the entire water column.

EFFECT OF TEMPERATURE ON LENGTH OF INCUBATION PERIOD

The length of the incubation period (d_i) is dependent on temperature of the water mass in which the eggs are developing, and may be predicted if the temperature coefficient for the rate of development is known.

The effect of temperature on the rate of development of jack mackerel eggs has been derived by two methods. In the first method, the eggs were taken from the sea shortly after they had been spawned, placed in a fish egg incubator (see appendix A) and observed at 4-hour intervals until they hatched. The temperature of the water in the incubator was maintained at about 14° C., the temperature of the sea water from which the eggs were collected. The observed hatching time was 108.5 hours. This experiment was repeated 1 year later at 15° C., with an observed hatching time of 84 hours.

The second method, which is indirect, was developed by Ahlstrom (1943) for the Pacific sardine and was also successfully used by Gamulin and Hure (1955) for sardines in the Mediterranean Sea. A series of arbitrarily chosen but precisely defined morphological stages is selected. Such a series of stages is described for jack mackerel in appendix B. The jack mackerel eggs from station samples are separated into stages and counted (Farris, 1958: table 2, p. 7–11).

Several successive days of spawning are indicated by the stage frequency modes present in each sample. A mode is interpreted as repre-

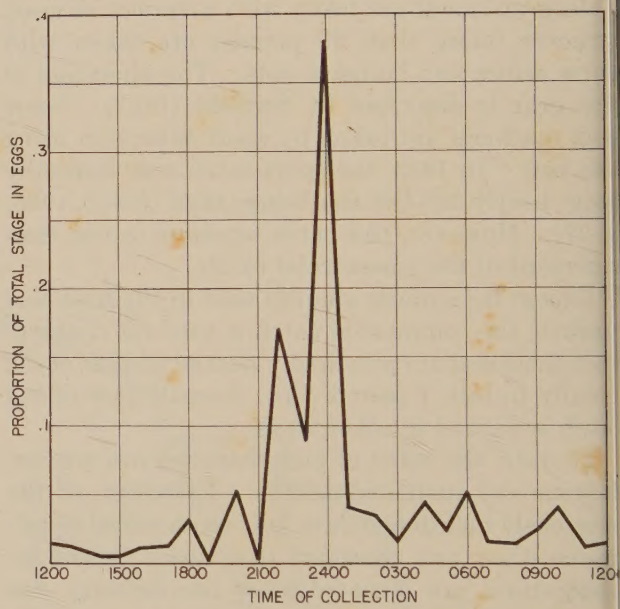


FIGURE 2.—Stage-I jack mackerel eggs collected in 195 by hour of collection. All stage-I eggs collected at particular hour are expressed as a proportion of the total stage-I eggs for the year.

senting 1 day's spawn, inasmuch as spawning is limited to a short period each night and the modes represent stages separable by a day as determined from incubation experiments.

The time of day at which spawning takes place was determined by plotting the relative abundance of precleavage eggs (stage I) against time of collection (fig. 2). The time the samples were collected is given in a report of the South Pacific Fishery Investigations (1952). These data showed the time of maximum spawning for jack mackerel was approximately midnight.

The age of the earliest stage is computed by subtracting the hour of collection from midnight. The age of the second mode is estimated by adding 24 hours to the age of the first mode, and the age

[2] c_i is derived as follows: $c_i=c'_i/d_i$ where c'_i=the standard number of eggs at the ith station; d_i=the time interval in days from spawning to hatching.

f subsequent modes is determined in the same manner.

Temperature data for the stations were supplied by the Scripps Institution of Oceanography. If the temperatures within the upper 30 meters of water did not vary by more than 0.1° C., the data from the station were used.

The effect of temperature on rate of development was shown by a regression of log hours of development against temperature for each stage.

Y=hours of development

X=temperature °C.

$$\text{Log } Y=a+bX$$

Separate regressions were made for three stages (table 1) so that the regression statistics might be compared. If a relation exists between rate of development and temperature, the slopes for the three regressions should be about the same. The Y-intercepts were not compared, since the lines are almost parallel and occur at different levels; the intercepts, as one would expect, are different.

TABLE 1.—*Temperature regression coefficients for the rate of development of jack mackerel eggs*

Statistic	Stage		
	V	VIII	IX
	2.996	3.047	3.257
	−0.093	−0.088	−0.088
(temperature °C.)	15.71	15.40	15.40
(log hours)	1.580	1.690	1.891

The close correspondence of the slopes for the three regressions indicates a uniform relation between developmental rate and temperature. By using the graph of the regression for the oldest stage (stage IX), the incubation period to the closest day could be predicted directly (fig. 3). This regression was used in determining the number of whole days elapsing in the egg stage (d_i) as mentioned above.

The incubation period (in hours) as predicted by the regression for stage-IX eggs was compared with the incubation period actually observed under conditions of controlled temperature (see p. 250). The close agreement between prediction and observation is shown in the following table:

Temperature (°C.)	Predicted hours	Observed hours
	106	108.5
	86.5	84

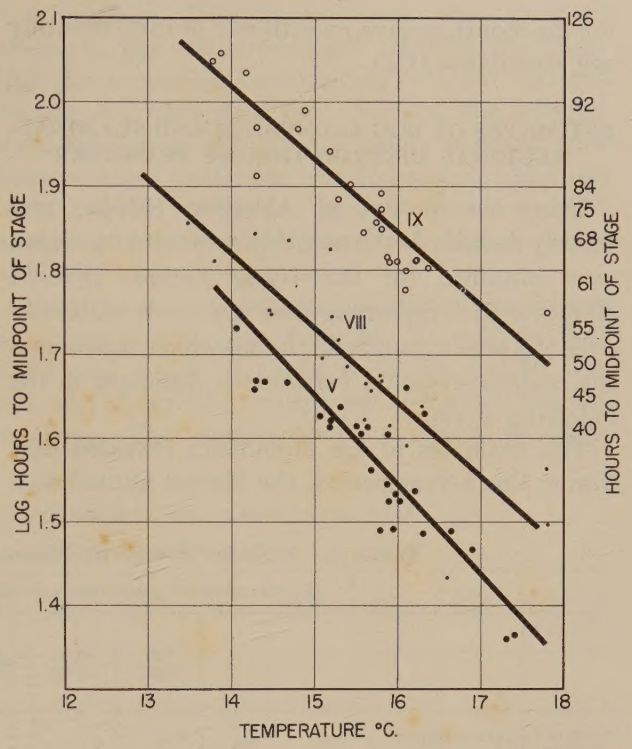


FIGURE 3.—Relation between temperature and rate of development for three stages of jack mackerel eggs.

The close agreement between incubation period predicted and actually observed lent confidence to the reliability of the indirect method.

The temperature-dependent incubation period (d_i) is used to compute the average number of eggs spawned per day at the ith station (c_i) in the following manner.

The standard number of eggs at the ith station (c'_i) is divided by d_i.

After computing the estimate of the average number of eggs spawned per day at the ith station of 10 square meters, the number of eggs is integrated over space to the surrounding stations by an area factor (w_i). The sample is then weighted on the basis of the area it represents. The boundaries of an area are formed by the perpendicular bisectors of lines drawn to the stations immediately surrounding the one under consideration.

The time factor (t_i) is derived by taking the number of days from the previous occupancy of the station to the occupancy of the station immediately succeeding the one under consideration and dividing by 2. The products ($c_i w_i t_i$) are summed

for the month to give an estimate of total monthly egg abundance (C_M).

ESTIMATES OF EGG ABUNDANCE AND SEASONAL-REGIONAL DISTRIBUTION OF SPAWNERS

Using the method of Ahlstrom (1954b) previously described, the monthly estimates by region were obtained for the 4-year period, 1951–54 (tables 2–5). Spawning does not occur uniformly over the area throughout the spawning season and the seasonal-regional variation is discussed in the following section.

The estimates of egg abundance revealed that during this 4-year period, the highest annual estimate (1951) was less than twice that of the lowes (1954). Furthermore, no trend was apparen from 1951 through 1954. Spawning averaged 66 trillion eggs per year, with a range of 873 trillio to 462 trillion.

The seasonal distribution of spawners was in ferred from the monthly estimates of egg abun dance and the number of eggs spawned per mont expressed as a percent of the annual total for eac year. Although the percentages have been car ried to hundredths, no statistical significanc should be attached to these postdecimal place which merely serve to indicate trace amounts o spawning. These figures are given in the last ro in tables 2 through 5.

TABLE 2.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1951*

[Cruise numbers in parentheses. No eggs taken during cruises 5101 and 5110 to 5112]

	Feb. (5102)	Mar. (5103)	Apr. (5104)	May (5105)	June (5106)	July (5107)	Aug. (5108)	Sept. (5109)	Annual total	Percent of total for all areas
North of Point Conception:										
Lines 40–57						1,365	2,907		4,272	
60–77			8,616	8,099	62,487	22,235	206	0	101,643	
Total and percent			8,616	8,099	62,487	23,600	3,113	0	105,915	12.1
Southern California:										
Line 80	44,060	50,497	2,476	47	7,915	1,228	53	12	106,288	
83	0		0	3,863	4,932			0	8,795	
85		40,344				0	890	0	41,234	
87	0		9,706	30,784	1,973		0		42,463	
90	2,829	48,338	33,804	22,298	13,712	10,412	7,334	15	138,742	
93	8,930	30,972	18,977	9,568	3,107	2,559	2,071	0	76,184	
Total and percent	55,819	170,151	64,963	66,560	31,639	14,199	10,348	27	413,706	47.40
Northern Baja California:										
Line 97	6,379	10,564	15,014	6,486	12,964	7,421	1,442	16	60,286	
100	1,970	7,469	19,735	18,484	3,761	21,484	907	0	73,810	
103		14,487	16,490	3,614	3,708			8	38,307	
105	0						307		307	
107		11,282	6,152	7,348	2,433			0	27,215	
Total and percent	8,349	43,802	57,391	35,932	22,866	28,905	2,656	24	199,925	22.91
Upper central Baja California:										
Line 110	0	20,092	19,439	7,263	8,754	890	424	0	56,862	
113	0	17,053	6,756	3,746	10,209				37,764	
115							445	0	445	
117	0	20,430	8,530	3,248	256				32,464	
120	0	291	4,781	2,318	14,993	341	115	0	22,839	
Total and percent	0	57,866	39,506	16,575	34,212	1,231	984	0	150,374	17.23
Lower central Baja California:										
Line 123	0	42	560	204	213	18	3	0	1,040	
127	0	42	30	41	40	0	0	0	153	
130	0	63	451	101	0	0	0	0	615	
133	0	28	369	430	0	16	0	0	843	
137	0	0	0	49	0	0	0	0	49	
Total and percent	0	175	1,410	825	253	34	3	0	2,700	.31
Southern Baja California:										
Line 140		165			0			0	165	
143		39			0			0	39	
147		0			0			0	0	
150		0			0			0	0	
Total and percent		204			0			0	204	.02
Grand total	64,168	272,198	171,886	127,991	151,457	67,969	17,104	51	872,824	
Percent[1]	7.35	31.19	19.69	14.66	17.35	7.79	1.96	0.01	100.00	

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see text above).

The regional (north-south) distribution of awning fish was inferred from the regional distribution of eggs. The number of eggs found in a ion was expressed as a percent of the total for regions (i.e., annual total). These figures are en in the last column in tables 2 through 5. e lines comprising each region are as follows:

gion	Area	Lines
	Northern California	40–77
	Southern California	80–93
	Northern Baja California	97–107
	Upper central Baja California	110–120
	Lower central Baja California	123–137
	Southern Baja California	140–157

A slightly different approach was used to elucidate the offshore-inshore distribution. Unlike the preceding section, only selected stations on selected lines were used, because the selected data were more quickly and easily handled, and because these particular selected stations had the most regular coverage, having been occupied almost every month throughout the 4 years studied.

Only those lines and stations that are multiples of 10 were used (e.g., lines 40, 50, and 60, but not 63, 67, or 73, and stations 40, 50, and 60, but not 45, 55, or 65), except for the most inshore stations. The standardized numbers of eggs

TABLE 3.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1952*

[Cruise numbers in parentheses. No eggs taken during cruises 5210 and 5211]

	Jan. (5201)	Feb. (5202)	Mar. (5203)	Apr. (5204)	May (5205)	June (5206)	July (5207)	Aug. (5208)	Sept. (5209)	Annual total	Percent of total for all areas
th of Point Conception:											
nes 40–57						0	49			49	
60–77				0	0	5, 278	9, 541	817	0	15, 636	
Total and percent				0	0	5, 278	9, 590	817	0	15, 685	2. 64
hern California:											
ne 80	0	161	1, 993	0	2, 769	22, 624	3, 262	793	0	31, 602	
83				107	6, 789	9, 290				16, 186	
85	0	0	0				3, 108	0	27	3, 135	
87				982	30, 880	4, 855				36, 717	
90	0	7, 625	54, 153	3, 075	30, 302	20, 144	2, 013	3, 034	2, 262	122, 608	
93	0	0	905	11, 713	9, 727	2, 944	8, 293	3, 001	109	36, 692	
Total and percent	0	7, 786	57, 051	15, 877	80, 467	59, 857	16, 676	6, 828	2, 398	246, 940	41. 64
thern Baja California:											
ne 97	33	1, 631	1, 691	34, 173	12, 380	8, 632	22, 058	1, 368	1, 600	83, 566	
100	1, 813	11, 532	12, 735	26, 325	10, 821	4, 440	4, 839	0	127	72, 632	
103				10, 914	24, 782	1, 428		27	8	37, 159	
105	173	29, 562	1, 278				7, 475			38, 488	
107				8, 899	12, 323	4, 323		15	13	25, 573	
Total and percent	2, 019	42, 725	15, 704	80, 311	60, 306	18, 823	34, 372	1, 410	1, 748	257, 418	43. 40
er central Baja California:											
ne 110	0	0	63	18, 950	26, 376	4, 877	751	0	0	51, 017	
113		0	325	1, 350	1, 944	2, 672	98	0	0	6, 389	
115	0									0	
117		0	61	132	539	2, 841	140	0	0	3, 713	
120	0	0	1, 313	1, 777	4, 145	523	0	25	0	7, 783	
Total and percent	0	0	1, 762	22, 209	33, 004	10, 913	989	25	0	68, 902	11. 63
er central Baja California:											
ne 123	0	0	1, 300	527	1, 978	239	0	0	0	4, 044	
127	0	0	0	0	0	0	0	0	0	0	
130	0	0	0	93	0	0	0	0	0	93	
133	0	0	0	0	0	0	0	0	0	0	
137	0	0	0	0	0	0	0	0	0	0	
Total and percent	0	0	1, 300	620	1, 978	239	0	0	0	4, 137	. 69
hern Baja California:											
ne 140		0								0	
143		0								0	
147		0								0	
150		0								0	
Total and percent		0								0	. 00
Grand total	2, 019	50, 511	75, 817	119, 017	175, 755	95, 110	61, 627	9, 080	4, 146	593, 082	
Percent [1]	0. 34	8. 52	12. 78	20. 07	29. 63	16. 04	10. 39	1. 53	0. 70	100. 0	

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

(instead of estimates of abundance) for these selected lines and stations were summed by 2-month intervals from February to July. The bimonthly totals for the lines were divided by the bimonthly totals for the entire area to give the bimonthly percentage of eggs found on the line. To estimate the offshore-inshore movements, stations 100 and seaward (offshore) were grouped together, stations 70–90 (intermediate) were grouped together, and stations 60-shore (inshore) were grouped together for each line. The station groups were summed bimonthly and the percentage of the bimonthly total for each of the three station groups was computed (tab 6, 7, 8, and 9). Table 10 presents a comparis of the estimates of relative regional abundan obtained from the standardized numbers of eg at selected stations on selected lines and t regional distribution based on estimates of abu dance using all data. Since the north-sou regional distribution indicated by the select data agreed with the north-south distributi indicated by all the data, no distortion w anticipated in using the selected data to reve the offshore-inshore distribution.

TABLE 4.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1953*

[Cruise numbers in parentheses. No eggs taken during cruises 5301, 5309, 5311, and 5312]

	Feb. (5302)	Mar. (5303)	Apr. (5304)	May (5305)	June (5306)	July (5307)	Aug. (5308)	Oct. (5310)	Annual total	Percen of tot for all areas
North of Point Conception:										
Lines 40–57										
60–77			12	0	6,075	1,947	1,619		9,653	
Total and percent			12	0	6,075	1,947	1,619		9,653	1.
Southern California:										
Line 80	0	0	3,783	22,633	3,774	5,570	288		36,048	
83	0	0	0	2,835	5,639	5,402	0	0	13,876	
85	0	0	0	152	590	3,252	18		4,012	
87	0	0	0	12,813	3,285	1,769	55		17,922	
90	0	0	5,512	60,199	1,241	7,016	378	47	74,393	
93	0	0	1,378	14,006	12,776	10,588	91	5	38,844	
Total and percent	0	0	10,673	112,638	27,305	33,597	830	52	185,095	25.
Northern Baja California:										
Line 97	0	0	4,327	19,550	36,880	4,556	602	0	65,915	
100	14,348	4,508	2,700	5,664	14,660	8,939	1,232	181	52,232	
103			5,722	21,840	16,905	4,601	519	0	49,587	
105	2,196	70,331							72,527	
107			66,907	19,528	14,200	10,606	2,015	0	113,256	
Total and percent	16,544	74,839	79,656	66,582	82,645	28,702	4,368	181	353,517	48.
Upper central Baja California:										
Line 110	9,585	27,732	59,051	5,847	1,228	2,250	1,122	0	106,815	
113	5,671	738	17,658	1,376	3,412	721	0	0	29,576	
115										
117	4,239	1,964	7,505	5,090	2,324	231	0	0	21,353	
120	1,743	0	3,779	12,936	247	124	0	0	18,829	
Total and percent	21,238	30,434	87,993	25,249	7,211	3,326	1,122	0	176,573	23.
Lower central Baja California:										
Line 123	0	0	0	6,701	81	0	0	0	6,782	
127	0	0	0	1,974	1,022	0	0	0	2,996	
130	0	0	0	1,327	140	0	0	0	1,467	
133	0	0	0	0	41	0	0	0	41	
137	0	0	0	0	8	0	0	0	8	
Total and percent	0	0	0	10,002	1,292	0	0	0	11,294	1.
Southern Baja California:										
Line 140										
143										
147										
150										
Total and percent										
Grand total	37,782	105,273	178,334	214,471	124,528	67,572	7,939	233	736,132	
Percent[1]	5.13	14.30	24.22	29.13	16.92	9.18	1.08	0.03	99.99	

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

TABLE 5.—*Estimated number (in billions) of jack mackerel eggs in survey area, 1954*

[Cruise numbers in parentheses. No eggs taken during cruise 5412]

	Jan. (5401)	Feb. (5402)	Mar. (5403)	Apr. (5404)	May (5405)	June (5406)	July (5407)	Aug. (5408)	Oct. (5410)	Annual total	Percent of total for all areas
rth of Point Conception:											
ines 40–57						82				82	
60–77				0	13, 610	7, 697	9, 685	42	0	31, 034	
Total and percent				0	13, 610	7, 779	9, 685	42	0	31, 116	6. 73
thern California:											
ine 80	0	0	0	43	14, 898	8, 166	4, 937	0	0	28, 044	
83	0	0	0	165	25, 822	13, 838	1, 239	31	0	41, 095	
85	0	0	0	0	3, 185	9, 797	221	0	0	13, 203	
87	0	0	0	17, 090	11, 430	3, 666	52	25	0	32, 263	
90	0	0	0	6, 529	3, 894	4, 905	9, 825	1, 596	0	26, 749	
93	0	0	0	24, 012	3, 822	1, 010	6, 053	874	16	35, 787	
Total and percent	0	0	0	47, 839	63, 051	41, 382	22, 327	2, 526	16	177, 141	38. 31
rthern Baja California:											
ine 97	0	0	7, 846	22, 602	4, 428	11, 690	1, 632	256	0	48, 454	
100	0	8, 034	40, 461	21, 729	10, 523	985	7, 289	539	0	89, 560	
103	0	878	2, 178	7, 505	11, 424	915	0	0	0	22, 900	
105											
107	0	13, 887	1, 220	4, 029	3, 717	1, 998	0	0	0	24, 851	
Total and percent	0	22, 799	51, 705	55, 865	30, 092	15, 588	8, 921	795	0	185, 765	40. 18
per central Baja California:											
ine 110	148	208	365	6, 451	6, 622	1, 820	2, 978	0	0	18, 592	
113	0	846	4, 137	4, 301	4, 861	538	70	40	0	14, 793	
115											
117	0	464	0	924	585	2, 011	0	33	0	4, 017	
120	0	0	208	2, 008	4, 547	4, 671	392	0	0	11, 826	
Total and percent	148	1, 518	4, 710	13, 684	16, 615	9, 040	3, 440	73	0	49, 228	10. 65
wer central Baja California:											
ine 123	0	0	0	124	12, 526	0	0	0	0	12, 650	
127	0	0	0	915	207	4	0	0	0	1, 126	
130	0	0	0	2, 160	0	0	0	0	0	2, 160	
133	0	0	0	2, 984	0	0	0	0	0	2, 984	
137	168	0	0		0	0	0	0	0	168	
Total and percent	168	0	0	6, 183	12, 733	4	0	0	0	19, 088	4. 13
thern Baja California:											
ine 140	0										
143	0										
147	0										
150	0										
Total and percent	0										
Grand total	316	24, 317	56, 415	123, 571	136, 101	73, 793	44, 373	3, 436	16	462, 338	
Percent [1]	0. 07	5. 26	12. 20	26. 73	29. 44	15. 96	9. 60	0. 74	0	100. 00	

[1] Hundredths of a percent are used so that trace amounts of spawning may be indicated (see p. 252).

Spawning in 1951 began in February. About percent of the total number of eggs for the ason were spawned during this month. Spawn- g rose to a peak of more than 30 percent of the tal in March, and then gradually declined until ne, when an increase occurred. Spawning de- eased thereafter, being negligible in September. awning during February and March was ntered about 150 miles offshore in region 2. uring the next 2 months spawning was more neral and no compact center was observed. awning had reached its widest distribution (most the eggs being taken between lines 60 and 120) April and May, and the center had moved inshore. During June and July the center was dispersed and offshore.

Spawning in 1952 began in January, when less than 1 percent of the total number of eggs were spawned, and rose to a peak of about 30 percent in May. It then declined to less than 1 percent in September and ceased altogether by October. The center of spawning was about 120 miles farther south during February and March than during the same period of 1951. Once again it was in the intermediate area. During April and May, spawning became heavier in region 3 and there was a strong inshore movement. During the final 2 months the spawners were grouped to

TABLE 6.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1951*

[Standard haul totals]

Line	Offshore stations (100-seaward)	Intermediate stations (90–70)	Inshore stations (60-shore)	Total	Percent
February-March:					
60	0	0	0	0	0
70	0	0	0	0	0
80	2,795	7,790	1,658	12,243	33.3
90	1,506	9,013	1,484	12,003	32.6
100	91	955	907	1,953	5.3
110	0	477	10,053	10,530	28.6
120	0	0	74	74	.2
Total	4,392	18,235	14,176	36,803	100.0
Percent	11.9	49.6	38.5	100.0	
April-May:					
60	0	14	0	14	.1
70	1,573	27	0	1,600	6.0
80	2,502	629	160	3,291	12.4
90	3,430	1,832	2,976	8,238	31.0
100	589	201	7,312	8,102	30.0
110	647	525	2,505	3,677	13.8
120	847	309	538	1,694	6.4
Total	9,588	3,537	13,491	26,616	99.7
Percent	36.0	13.3	50.7	100.0	
June-July:					
60	1,490	222	6	1,718	11.3
70	137	2,613	1,414	4,164	27.5
80	40	1,100	664	1,804	11.9
90	945	284	2,399	3,628	23.9
100	15	1,134	802	1,951	12.9
110	0	765	420	1,185	7.8
120	0	648	56	704	4.6
Total	2,627	6,766	5,761	15,154	99.9
Percent	17.3	44.6	38.0	99.9	

TABLE 7.—*Relative north-south, inshore-offshore distribution of jack mackerel eggs by 2-month intervals for 1952*

[Standard haul totals]

Line	Offshore stations (100-seaward)	Intermediate stations (90–70)	Inshore stations (60-shore)	Total	Percent
February-March:					
60	(1)	(1)	(1)	(1)	(1)
70	(1)	(1)	(1)	(1)	(1)
80	11	377	0	388	2.8
90	(1)	6,665	0	6,665	48.5
100	(1)	4,528	2,027	6,555	47.7
110	(1)	4	2	6	<0.1
120	(1)	142	0	142	1.0
Total	11	11,716	2,029	13,756	100.1
Percent	0.1	85.2	14.7	100.0	
April-May:					
60	(1)	0	0	0	0
70	(1)	0	0	0	0
80	223	0	0	223	1.0
90	205	3,635	4,805	8,645	37.1
100	82	1,724	6,107	7,913	34.0
110	(1)	5,495	567	6,062	26.0
120	(1)	293	159	452	1.9
Total	510	11,147	11,638	23,295	100.0
Percent	2.2	47.8	50.0	100.0	
June-July:					
60	5	535	36	576	3.6
70	429	270	0	699	4.4
80	3,495	2,235	1,098	6,828	42.8
90	74	3,766	950	4,790	30.0
100	161	601	1,208	1,970	12.4
110	(1)	398	665	1,063	6.7
120	(1)	0	13	13	.1
Total	4,164	7,805	3,970	15,939	100.0
Percent	26.1	49.0	24.9	100.0	

[1] Region not occupied.

TABLE 8.—*Relative north-south, inshore-offshore distri*
tion of jack mackerel eggs by 2-month intervals for 195

[Standard haul totals]

Line	Offshore stations (100-seaward)	Intermediate stations (90–70)	Inshore stations (60-shore)	Total	Perce
February-March:					
60	(1)	(1)	(1)	(1)	(1)
70	(1)	(1)	(1)	(1)	(1)
80	(1)	0	0	0	
90	(1)	0	0	0	
100	(1)	1,551	4,445	5,996	
110	(1)	1,138	4,399	5,537	
120	(1)	(1)	228	228	
Total		2,689	9,072	11,761	10
Percent		22.9	77.1	100.0	
April-May:					
60	0	0	0	0	
70	(1)	0	8	8	
80	1,149	2,452	18	3,619	1
90	1,725	5,631	298	7,654	2
100	(1)	580	805	1,385	
110	(1)	5,437	8,721	14,158	4
120	(1)	403	3,679	4,082	1
Total	2,874	14,503	13,529	30,906	10
Percent	9.3	46.9	43.8	100.0	
June-July:					
60	(1)	0	96	96	
70	85	116	61	262	
80	21	703	657	1,381	1
90	(1)	423	364	787	1
100	151	952	3,456	4,559	5
110	(1)	(1)	562	562	
120	(1)	17	10	27	
Total	257	2,211	5,206	7,674	10
Percent	3.3	28.8	67.8	99.9	

[1] Region not occupied.

TABLE 9.—*Relative north-south, inshore-offshore distrib*
tion of jack mackerel eggs by 2-month intervals for 1954

[Standard haul totals]

Line	Offshore stations (100-seaward)	Intermediate stations (90–70)	Inshore stations (60-shore)	Total	Percen
February-March:					
60	(1)	(1)	(1)	(1)	(1)
70	(1)	(1)	(1)	(1)	(1)
80	(1)	0	0	0	0
90	(1)	0	0	0	0
100	(1)	4,167	1,207	5,374	96
110	(1)	0	185	185	3
120	(1)	12	0	12	0
Total		4,179	1,392	5,571	100
Percent		75.0	25.0	100.0	
April-May:					
60	43	180	0	223	1
70	(1)	745	40	785	5
80	(1)	2,326	19	2,345	17
90	(1)	2,051	616	2,667	19
100	987	1,206	1,151	3,344	24
110	(1)	351	3,308	3,659	27
120	(1)	423	36	459	3
Total	1,030	7,282	5,170	13,482	100
Percent	7.6	54.0	38.3	99.9	
June-July:					
60	50	816	0	866	11
70	(1)	48	784	832	11
80	347	743	936	2,026	27
90	(1)	404	1,931	2,335	31
100	(1)	135	367	502	6
110	(1)	92	302	394	5
120	(1)	270	153	423	5
Total	397	2,508	4,473	7,378	99
Percent	5.4	34.0	60.6	100.0	

[1] Region not occupied.

ABLE 10.—*Comparison of estimates of regional distribution ing selected stations on selected lines and all data, 1951–54*

Line	February–March	April–May	June–July	Selected stations		All stations (percent)
				Total	Percent	
51:						
30	0	14	1,718	1,732	[1] 2.20	12.13
70	0	1,600	4,164	5,764	7.34	
80	12,243	3,291	1,804	17,338	22.07	22.77
90	12,003	8,238	3,628	23,869	30.38	31.53
100	1,953	8,102	1,951	12,006	15.28	16.00
110	10,530	3,677	1,185	15,392	19.59	14.61
120	74	1,694	704	2,472	3.15	2.95
Total				78,573	100.01	99.99
52:						
30	([2])	0	576	576	1.09	2.64
70	([2])	0	699	699	1.32	
80	388	223	6,828	7,439	14.04	14.78
90	6,665	8,645	4,790	20,100	37.93	40.95
100	6,555	7,913	1,970	16,438	31.02	29.31
110	6	6,062	1,063	7,131	13.46	10.31
120	142	452	13	607	1.15	2.01
Total				52,990	100.01	100.00
53:						
30	([2])	0	96	96	0.19	1.31
70	([2])	8	262	270	.54	
80	0	3,619	1,381	5,000	9.91	9.76
90	0	7,654	787	8,441	16.77	24.34
100	5,996	1,385	4,559	11,940	23.72	39.07
110	5,537	14,158	562	20,257	40.24	21.43
120	228	4,082	27	4,337	8.62	4.09
Total				50,341	99.99	100.00
54:						
30	([2])	223	866	1,089	4.12	6.73
70	([2])	785	832	1,617	6.12	
80	0	2,345	2,026	4,371	16.54	24.79
90	0	2,667	2,335	5,002	18.92	24.01
100	5,374	3,344	502	9,220	34.88	29.70
110	185	3,659	394	4,238	16.03	8.09
120	12	459	423	894	3.38	6.69
Total				26,431	99.99	100.01

[1] Hundredths of a percent are used so trace amounts of spawning may be indicated (see p. 252).
[2] Region not occupied.

he north in region 2 and were farther offshore in he intermediate area.

Spawning in 1953 began in February and rose o a peak of nearly 30 percent of the total in May, nd then declined. Only small numbers of eggs ere taken in October. Early spawning was entered in region 3, with a fair amount in region 2. he center of spawning was about 240 miles rther south than the early spawning of 1951, nd most of the spawning was inshore. From is center, spawning moved both north and south nd somewhat offshore to the intermediate area. uring the final 2 months, the center of spawning as again in region 3 and inshore.

The monthly distribution of spawning for 1954 very similar to that for 1953. Spawning exended from January to October and reached a eak of nearly 30 percent of the total in May. arly spawning was centered in region 3 about 50 miles offshore (intermediate area) and no eggs were taken off California. In the next 2 months the heavier concentrations extended north to region 2 and south to the northern edge of region 4, with some inshore movement. During the final 2 months the center shifted northward to region 2 and inshore. The distribution and relative abundance of jack mackerel eggs for 1951–54 are illustrated in Farris (1958; figs. 3–6).

The remarkable similarity of monthly distribution of spawning in 1952 through 1954 (peak month, May) is illustrated in figure 4. The year

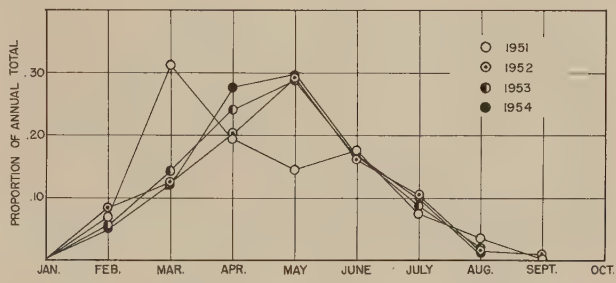


FIGURE 4.—Proportion of annual spawning of jack mackerel, by months, 1951–54.

1951 appears to have been an anomalous year with an early peak of spawning in March. The proportion of spawning that occurred during the peak month of each year, including 1951, was approximately three-tenths of the total for the year. Furthermore, over seven-tenths of the spawning for any year occurred during the first 5 months.

Of the 4 years studied, 1951 had the highest proportion of the annual total number of eggs in region 1. High proportions of the annual total eggs were found in regions 3 and 4 during 1953, with a small proportion being taken in regions 1 and 2.

BOUNDARIES OF THE SPAWNING AREA

The northern and western boundaries of jack mackerel spawning during August and September were established by expedition *Norpac*, an extensive study of the north Pacific in 1955 conducted by the California Cooperative Oceanic Fisheries Investigations and other agencies (Ahlstrom, 1956: p. 39; Ahlstrom and Kramer, 1957: p. 55). These boundaries may be less certain than the others because the study of the area was more limited in time. The eastern and southern

boundaries were established from data collected on regular survey cruises of the California Cooperative Oceanic Fisheries Investigations (Farris, 1958). Spawning areas are approximately bounded by the 26th parallel on the south, the 45th parallel on the north, the coast of North America on the east, and the 150th meridian on the west.

SOURCES OF ERROR AND BIAS IN SAMPLING EGGS

These data and subsequent interpretations are subject to errors inherent in the collection procedures. The types of error investigated and evaluated were (1) completeness of retention of eggs by the nets; (2) completeness of sampling of the vertical range; (3) sampling error owing to a variable distribution of eggs in space and time; and (4) incomplete sampling of the horizontal range of jack mackerel spawning.

RETENTION OF EGGS BY THE NETS

The eggs are fully retained by the net once they are in it, because the plankton nets have a stretched mesh of 0.5–0.7 mm. (Ahlstrom, 1953), and the spherical eggs range in diameter from 0.9–1.1 mm (Ahlstrom and Ball, 1954). It would appear, therefore, that no eggs are lost through the mesh of the sampling net.

SAMPLING OF THE VERTICAL RANGE

Investigation of the vertical distribution of jack mackerel eggs (Ahlstrom, 1959: table 7) with a horizontally towed closing net reveals that most of the eggs occur in the upper 40 meters of water. Jack mackerel eggs have rarely been taken below 100 meters, and never below 140 meters. The bulk of the eggs have occurred above the thermocline. Since plankton hauls are routinely made from a depth of 140 meters, which has always included the thermocline depth, it seems likely that the vertical distribution of jack mackerel eggs is completely sampled.

VARIABLE DISTRIBUTION OF EGGS

The distribution of jack mackerel eggs is variable with respect to both time and space. An illustrative example is given in figure 5. The standard numbers of jack mackerel eggs for line 97 have been plotted by station for 4 months.

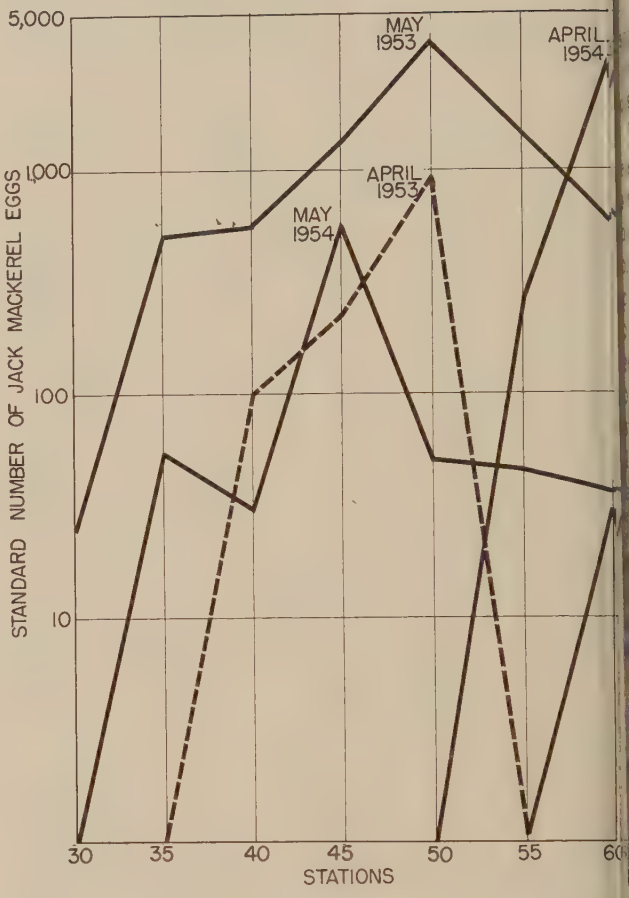


FIGURE 5.—Standard numbers of jack mackerel eggs found on line 97 during 4 months.

The average number of eggs per station by month is given below.

Year:	*April*	*May*
1953	181	1,116
1954	762	143

The average station on line 97 in May 1953 contained six times as many eggs as the average station in the preceding month. Assuming that this change was rectilinear in time, the estimate would be altered considerably, depending on which day of the month the sample was taken.

Spatial variability is indicated by the data for April 1954, in which a change of 1 order of magnitude occurs within 20 miles. There is at least one such combination of adjacent stations having as great a change in the distribution of jack mackerel eggs for each cruise illustrated. The grid of stations occupied is too coarse except for fairly rough estimates of egg abundance. Although more frequent sampling of more closely

aced stations is highly desirable, such sampling nnot be effected, since it would raise the current st of sampling prohibitively.

The monthly sampling of the California Coop-ative Oceanic Fisheries Investigations grid of ations has all but precluded the simple assess-ent of the error associated with these estimates abundance. Although the construction of the oper statistical model was not within the scope this investigation, I was able to make an timate of the error arising from the practice linear interpolation of egg numbers in time and ace. This calculation was possible because in 53 and 1954 stations which were only 20 miles art were occupied, and the samples contained ck mackerel eggs. In 1952, a few stations ntaining jack mackerel eggs were occupied in te March.

The errors arising from stratification in space .e., spacing sampling stations 40 miles apart) and me (i.e., spacing sampling cruises 1 month apart) ere considered. Standard numbers of eggs for ations 20 miles apart—obtained by linear inter-lation of values obtained from stations 40 miles art—were compared with values actually ob-rved. In like manner, standard numbers of gs for stations sampled at intervals of one-half onth—obtained by linear interpolation of ob-rved values from stations sampled at monthly tervals—were compared with the values actually served. The differences should be zero if no ror arises from linear interpolation through space d time. Since the average difference cannot be pected actually to equal zero, owing to sampling riability, the 95-percent confidence limits for th estimates were computed. These limits ould include zero.

The error arising from spacing the sampling ations 40 miles apart was estimated using data m selected stations on selected lines. (Stations ving no eggs were not used.) These stations ere placed 20 miles apart. An estimated value as given for every other station by a process of ear interpolation of values between the remain-g stations which were 40 miles apart. These terpolated values were then compared with the tual number of eggs found at the stations and e difference (Δ_i) calculated. (Δ_i=observed andard number of jack mackerel eggs minus timated number of jack mackerel eggs.) The ltas were averaged to give $\bar{\Delta}$, the average differ-ence between the observed standard number of jack mackerel eggs and the number calculated by linear interpolation.

The frequency distribution of Δ_i was plotted and appeared to be normally distributed (fig. 6).

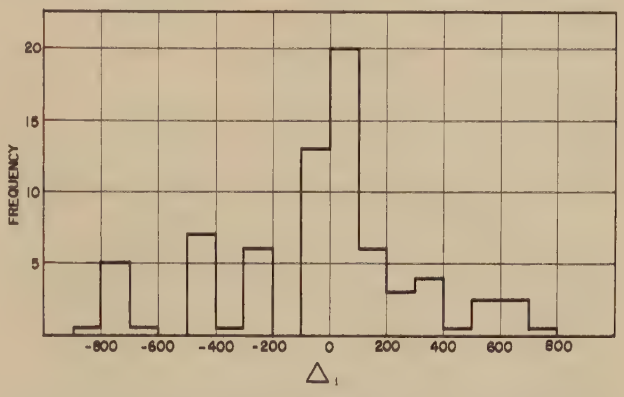


FIGURE 6.—Frequency distribution of Δ_i (the difference between observed and estimated numbers of jack mackerel eggs).

Therefore Δ_i was considered to be a normally distributed random variable with mean $\bar{\Delta}$ and variance s^2.

Statistic	Value	Description
$\bar{\Delta}$	7.8	Average difference.
$s^2_{\Delta_i}$	518,956	Variance of the individual differences.
s_{Δ_i}	720	Standard deviation of the individual differences.
$s_{\bar{\Delta}}$	74.2	Standard deviation of the mean.
n	94	Number of differences observed.

$$-137.2 \leq \bar{\Delta} \leq 152.8$$

The average difference is close to zero. The wide confidence limits indicate the high variability associated with any one observation.

The Δ_i were compared with the size of each ith haul to determine whether the differences were related to population size (fig. 7). No relation was evident and it was concluded that the Δ_i were not related to population size.

The error arising from stratification in time was estimated by considering the standard numbers of jack mackerel eggs taken at selected stations during cruises spaced about 2 weeks apart (March, late March, and April, 1952). By linear interpolation of the number of eggs taken at a station between the March and April occupancies, an estimate of the number of eggs that should occur at the station during the late March occupancy was obtained. This estimated number was then

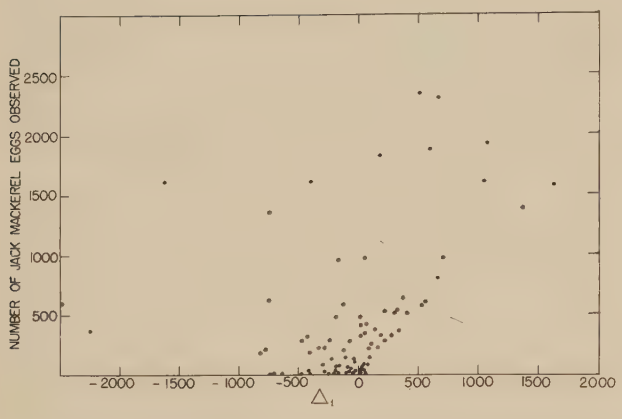


FIGURE 7.—Relation of Δ_i (the difference between observed and estimated numbers of jack mackerel eggs) and the number of eggs observed at the ith station.

compared with the number actually observed and the difference (Δ_i) noted. (Δ_i=the standard number of jack mackerel eggs estimated by linear interpolation minus the number actually observed.) The differences were averaged to give a mean difference ($\bar{\Delta}$) between the estimated number of eggs and the actual number of eggs. The average difference ($\bar{\Delta}$) was minus 11, with a variance of 3370. The 95-percent confidence limits on $\bar{\Delta}$ are minus 47 to plus 25.

Although the individual errors arising from the practice of linear interpolation of jack mackerel eggs in time and space were high and variable, the average error tended toward zero. I concluded that for a large number of samples (i.e., interpolations) the error arising from linear interpolation of the number of eggs in time and space was negligible.

A further indication of irregularities in the spatial and/or temporal distribution would be the nonconcurrence of eggs and larvae in the sampling areas. In table 11 the occurrences of eggs and larvae, by regions, are compared. In region 1

TABLE 11.—*Occurrences of jack mackerel eggs and larvae, by month and region, 1952–54*

Date	Region 1[1]			Region 2			Region 3			Region 4			Region 5			Region 6		
	Stations occupied	Stations with eggs	Stations with larvae	Stations occupied	Stations with eggs	Stations with larvae	Stations occupied	Stations with eggs	Stations with larvae	Stations occupied	Stations with eggs	Stations with larvae	Stations occupied	Stations with eggs	Stations with larvae	Stations occupied	Stations with eggs	Stations with larvae
1952:																		
January				28	0	0	19	3	1	22	0	0	25	0	0			
February				27	5	3	20	7	0	30	0	0	18	0	0	14	0	0
March				25	4	6	20	8	12	25	7	11	21	1	3			
April	18	0	0	37	14	12	31	24	26	36	17	13	33	5	10			
May	23	0	0	50	31	28	43	35	37	40	30	25	31	5	7			
June	34	4	3	58	36	42	58	34	42	42	21	18	30	3	3			
July	46	14	4	38	31	22	32	27	25	36	9	11	27	0	2			
August	15	2	1	22	10	8	17	3	9	30	1	0	15	0	0			
September	21	0	0	22	6	8	17	5	3	19	0	0	15	0	0			
October	18	0	0	21	0	1	15	0	2	19	0	0	15	0	0			
November	18	0	0	22	0	0	16	0	0	21	0	0	14	0	0			
December																		
Total	193	20	8	350	137	130	288	146	157	320	85	78	244	14	25	14	0	0
1953:																		
January				34	0	0	20	0	0	16	0	0	13	0	0	13	0	0
February				35	0	1	17	2	4	24	8	5	19	0	0			
March				36	0	3	17	9	13	29	11	12	31	0	1			
April	20	1	0	61	9	8	41	30	21	38	31	18	35	0	0			
May	30	0	0	63	41	23	38	35	22	37	28	21	35	8	10			
June	26	18	2	56	31	20	43	33	34	40	19	23	31	11	9			
July	24	9	2	38	21	15	20	14	8	21	8	5	19	0	0			
August	19	6	1	38	11	5	20	8	3	21	3	2	20	0	0			
September				18	0	1				24	0	0						
October				18	2	3	16	2	6	21	0	4	14	0	1			
November				19	0	0												
December				28	0	0	17	0	0	21	0	0	16	0	0			
Total	119	34	5	444	115	79	249	133	111	292	108	90	233	19	21	13	0	0
1954:																		
January	2	0	0	42	0	0	22	0	0	27	1	0	23	1	2	18	0	0
February	2	0	0	37	0	0	24	11	3	31	5	4	22	0	1			
March	2	0	0	35	0	0	32	15	19	48	8	19	36	0	0			
April	18	0	0	51	16	13	39	29	26	52	24	19	38	8	15			
May	19	8	2	54	33	23	42	34	34	52	25	29	38	9	8			
June	36	13	9	48	31	20	39	25	34	51	17	22	35	1	6			
July	19	8	6	37	13	11	20	9	9	22	6	3	20	0	1			
August	22	1	2	39	10	13	19	6	8	22	2	0	20	0	0			
September																		
October	2	0	0	38	2	1	22	0	0	23	0	0	20	0	1			
November																		
December				36	0	0	16	0	0	26	0	0	19	0	0	18	0	0
Total	122	30	19	417	105	81	275	129	133	354	88	96	271	19	34	36	0	0

[1] See page 253.

here are more occurrences of eggs than of larvae, while in region 5, the converse is true. This may indicate southern transport of the larvae by the California Current.

The high proportion of stations occupied in region 2 at which eggs or larvae were taken is a further indication (see also tables 3, 4, and 5) that this is the region of maximum spawning activity.

A comparison of total occurrences of eggs with total occurrences of larvae is interpreted as indicative of a distribution more regular than that encountered for other pelagic eggs and larvae (e.g., sardines).

SAMPLING OF THE HORIZONTAL RANGE OF SPAWNING

To determine the proportion of the total annual spawning which might be missed by failure to extend the sampling far enough seaward, the proportion of eggs taken beyond stations 90 (the usual seaward extent of sampling) was computed (see column 100—seaward in tables 6, 7, 8, and 9). This areal proportion was multiplied by the proportion of annual spawning that occurred during the appropriate 2-month interval (tables 2, 3, 4, and 5) to give a bimonthly estimate of the proportion of annual spawning which might be missed by failure to extend the sampling sufficiently seaward (table 12). It would appear that at least 21 percent of the annual spawning has occurred seaward of stations 90, and that a portion of the eggs has been missed in those years when monthly sampling was not extended beyond that point.

TABLE 12.—*Proportion of jack mackerel spawning occurring seaward of station 90, by 2-month intervals, 1951–54*

Month	1951	1952	1953	1954
February–March	0.05	(1)	(1)	(1)
April–May	.12	0.01	0.05	0.04
June–July	.04	.07	.01	.01
Annual total	.21	.08	.06	.05

[1] Region not occupied.

Data from the previously mentioned *Norpac* indicate that the proportion of eggs spawned in northern waters (north of line 40) may be between and 2 percent of the annual total. This proportion is minimal, since spawning occurs in periods other than that covered by *Norpac*. This estimate was determined by estimating the total spawning in the region for the period August–early September (8,655 billion eggs) and comparing that figure with the estimated number of eggs spawned in 1954 (464,452 billion) and 1951 (874,322 billion). It is therefore inferred that an appreciable amount of annual spawning may occur west of stations 90 but a lesser amount takes place north of line 40.

EFFECTS OF TEMPERATURE ON SPAWNING

Temperature may have at least two effects on the jack mackerel. It influences the rate at which the eggs develop (see p. 250), and it may well govern when and where the adults spawn.

To determine the effect of temperature on the spawning jack mackerel, temperatures at 10-meter depths were tabulated by 0.5° C. intervals for all stations where jack mackerel eggs were taken in 1951 through 1954 (table 13). The temperature at this depth is generally representative of the strata in which jack mackerel eggs are most abundant. These data were examined also for seasonal effect by dividing the year into an early (January–May) and a late (June–December) period. The effect of temperature on the size of haul was also examined by dividing the samples into two categories: hauls containing 1–100 eggs and hauls containing 101 eggs and more.

A seasonal trend toward higher spawning temperatures in the late summer with a greater temperature range was indicated (table 14 and figure 8). The data were then tabulated by

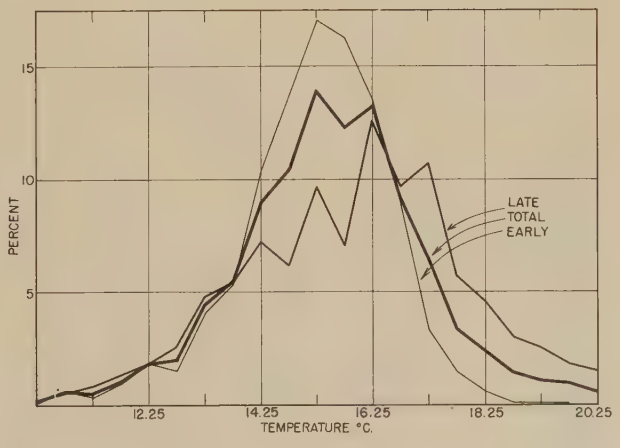


FIGURE 8.—Percentage of early (January-May) stations, of late (June–December) stations, and of the total stations having jack mackerel eggs, shown by 0.5° C. temperature intervals measured at 10-meter depth.

TABLE 13.—*Temperature distribution at 10 meters of stations having jack mackerel eggs, by season and size of sample, 1951–54*

[In 0.5° C. intervals]

Temperature	1951			1952			1953			1954			Total			Percent of total
	Early	Late	Total	Early	Late	Total	Early	Late	Total	Early	Late	Total	Early	Late	Total	
1–100 eggs:																
10.00–10.49	0	0	0	0	1	1	1	0	1	0	0	0	1	1	2	0.
10.50–10.99	0	2	2	0	0	0	4	1	5	1	0	1	5	3	8	1.
11.00–11.49	1	2	3	0	1	1	0	1	1	1	1	2	2	5	7	1.
11.50–11.99	2	1	3	0	1	1	1	1	2	3	3	6	6	6	12	1.
12.00–12.49	3	4	7	1	1	2	4	4	8	0	1	1	8	10	18	2.
12.50–12.99	3	2	5	1	5	6	2	4	6	1	0	1	7	11	18	2.
13.00–13.49	9	5	14	3	4	7	1	5	6	2	4	6	15	18	33	4.
13.50–13.99	10	3	13	7	2	9	6	7	13	1	3	4	24	15	39	5.
14.00–14.49	6	6	12	4	3	7	7	5	12	10	6	16	27	20	47	6.
14.50–14.99	4	3	7	4	6	10	5	5	10	11	3	14	24	17	41	5.
15.00–15.49	10	11	21	13	7	20	10	10	20	17	6	23	50	34	84	11.
15.50–15.99	15	11	26	6	5	11	4	6	10	13	1	14	38	23	61	8.
16.00–16.49	17	17	34	11	15	26	8	10	18	17	9	26	53	51	104	14.
16.50–16.99	14	8	22	8	14	22	4	4	8	13	12	25	39	38	77	10.
17.00–17.49	9	12	21	2	20	22	1	6	7	8	6	14	20	44	64	9.
17.50–17.99	6	6	12	1	3	4	1	5	6	0	6	6	8	20	28	3.
18.00–18.49	5	3	8	0	5	5	0	5	5	0	7	7	5	20	25	3.
18.50–18.99	1	6	7	0	1	1	0	3	3	0	6	6	1	16	17	2.
19.00–19.49	0	2	2	0	1	1	0	5	5	0	2	2	0	10	10	1.
19.50–19.99	0	1	1	0	0	0	0	3	3	1	6	7	1	10	11	1.
20.00–20.49	0	0	0	0	1	1	0	2	2	0	4	4	0	7	7	1.
20.50–20.99	0	1	1	0	0	0	0	1	1	0	0	0	0	2	2	.
Total	115	106	221	61	96	157	59	93	152	99	86	185	334	381	715	99.
101+ eggs:																
10.00–10.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.50–10.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.00–11.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.50–11.99	0	1	1	0	0	0	1	1	2	0	0	0	1	2	3	.
12.00–12.49	2	1	3	1	0	1	3	0	3	0	0	0	6	1	7	1.
12.50–12.99	1	2	3	0	1	1	2	0	2	2	2	4	5	5	10	1.
13.00–13.49	4	2	6	5	5	10	2	2	4	6	2	8	17	11	28	4.
13.50–13.99	7	8	15	2	2	4	6	3	9	3	5	8	18	18	36	5.
14.00–14.49	19	11	30	8	1	9	13	6	19	14	6	20	54	24	78	11.
14.50–14.99	14	3	17	25	10	35	21	6	27	24	2	26	84	21	105	15.
15.00–15.49	29	3	32	8	7	15	25	11	36	23	4	27	85	25	110	16.
15.50–15.99	23	4	27	22	7	29	24	8	32	22	1	23	91	20	111	16.
16.00–16.49	20	9	29	14	6	20	7	8	15	13	3	16	54	26	80	11.
16.50–16.99	6	6	12	7	9	16	5	4	9	13	2	15	31	21	52	7.
17.00–17.49	1	4	5	2	6	8	2	8	10	1	3	4	6	21	27	4.
17.50–17.99	1	3	4	1	7	8	1	5	6	0	0	0	3	15	18	2.
18.00–18.49	0	4	4	0	1	1	0	3	3	0	0	0	0	8	8	1.
18.50–18.99	0	0	0	0	0	0	0	2	2	0	0	0	0	2	2	.
19.00–19.49	0	0	0	0	1	1	0	4	4	0	0	0	0	5	5	.
19.50–19.99	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	.
20.00–20.49	0	0	0	0	1	1	0	0	0	0	1	1	0	2	2	.
20.50–20.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	127	61	188	95	64	159	112	71	183	121	32	153	455	228	683	100.

TABLE 14.—*Summary: Distribution of temperatures at 10 meters of stations having jack mackerel eggs, by season and size of sample, 1951–54*

[In 0.5°C. intervals]

Temperature	Early season				Late season				Season total			
	1–100 eggs	101+ eggs	Total	Percent of total	1–100 eggs	101+ eggs	Total	Percent of total	1–100 eggs	101+ eggs	Total	Percent of total
10.00–10.49	1	0	1	0.1	1	0	1	0.2	2	0	2	0.1
10.50–10.99	5	0	5	.6	3	0	3	.5	8	0	8	.6
11.00–11.49	2	0	2	.3	5	0	5	.8	7	0	7	.5
11.50–11.99	6	1	7	.9	6	2	8	1.3	12	3	15	1.1
12.00–12.49	8	6	14	1.8	10	1	11	1.8	18	7	25	1.8
12.50–12.99	7	5	12	1.5	11	5	16	2.6	18	10	28	2.0
13.00–13.49	15	17	32	4.1	18	11	29	4.8	33	28	61	4.4
13.50–13.99	24	18	42	5.3	15	18	33	5.4	39	36	75	5.4
14.00–14.49	27	54	81	10.3	20	24	44	7.2	47	78	125	8.9
14.50–14.99	24	84	108	13.7	17	21	38	6.2	41	105	146	10.4
15.00–15.49	50	85	135	17.1	34	25	59	9.7	84	110	194	13.9
15.50–15.99	38	91	129	16.3	23	20	43	7.1	61	111	172	12.3
16.00–16.49	53	54	107	13.6	51	26	77	12.6	104	80	184	13.2
16.50–16.99	39	31	70	8.9	38	21	59	9.7	77	52	129	9.2
17.00–17.49	20	6	26	3.3	44	21	65	10.7	64	27	91	6.5
17.50–17.99	8	3	11	1.4	20	15	35	5.7	28	18	46	3.3
18.00–18.49	5	0	5	.6	20	8	28	4.6	25	8	33	2.4
18.50–18.99	1	0	1	.1	16	2	18	3.0	17	2	19	1.4
19.00–19.49	0	0	0	0	10	5	15	2.5	10	5	15	1.1
19.50–19.99	1	0	1	.1	10	1	11	1.8	11	1	12	.9
20.00–20.49	0	0	0	0	7	2	9	1.5	7	2	9	.6
20.50–20.99	0	0	0	0	2	0	2	.3	2	0	2	.1
Total	334	455	789	100.0	381	228	609	100.0	715	683	1,398	100.1

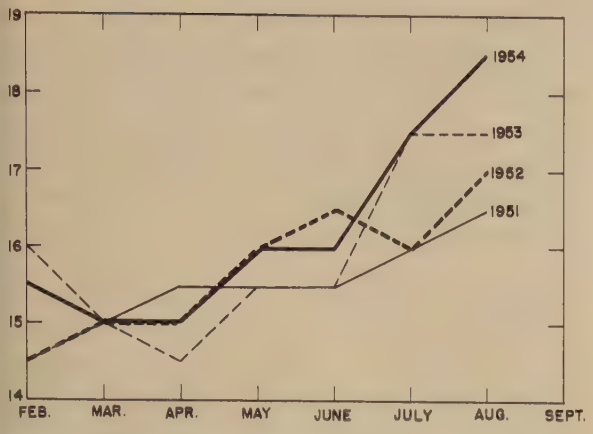


FIGURE 9.—Monthly median temperatures at 10 meters, at which jack mackerel eggs were spawned.

monthly intervals and the median temperatures at 10 meters computed for each month. The monthly median temperatures are shown in figure 9 and indicate that spawning generally occurs at lower temperatures in spring than in late summer. The within-year median temperature shift is greater than the between-year temperature variation (see below).

The data from table 13 are summarized in tables 15 and 16. A difference in optimum spawning temperature between small hauls (1–100 eggs) and large hauls (101 eggs and more) is noted (fig. 10). The reason for the difference is that a large proportion of the large hauls were taken during the peak of the season (April and May), and have therefore a more restricted temperature distribution.

The early, late, and annual distributions of temperature at a depth of 10 meters, by 0.5° C. increments, for all stations occupied in 1951–54 are given in table 17. These differ from the distribution of temperatures at which jack mackerel were taken in two ways: their temperature range is greater, and they show less tendency to cluster about a central value.

TABLE 15.—*Summary: Distribution of temperatures at 10 meters of stations having jack mackerel eggs, by size of sample, 1951–54*

[In 0.5° C. intervals]

Temperature	1–100 eggs	101+ eggs	Total samples	Percent of total
10.00–10.49	2	0	2	0.1
10.50–10.99	8	0	8	.6
11.00–11.49	7	0	7	.5
11.50–11.99	12	3	15	1.1
12.00–12.49	18	7	25	1.8
12.50–12.99	18	10	28	2.0
13.00–13.49	33	28	61	4.4
13.50–13.99	39	36	75	5.4
14.00–14.49	47	78	125	9.0
14.50–14.99	41	105	146	10.4
15.00–15.49	84	110	194	13.9
15.50–15.99	61	111	172	12.3
16.00–16.49	104	80	184	13.2
16.50–16.99	77	52	129	9.2
17.00–17.49	64	27	91	6.5
17.50–17.99	28	18	46	3.3
18.00–18.49	25	8	33	2.4
18.50–18.99	17	2	19	1.4
19.00–19.49	10	5	15	1.1
19.50–19.99	11	1	12	.9
20.00–20.49	7	2	9	.6
20.50–20.99	2	0	2	.1
Total	715	683	1,398	100.2

TABLE 16.—*Average temperatures at 10 meters during jack mackerel spawning, by season and size of sample, 1951–54*

Sample size and spawning season	Mean	Median	Mode
1951:			
1–100 eggs:			
Early	15.5	15.5	16.0
Late	15.8	16.0	16.0
Annual average	15.7	15.5	16.0
101+ eggs:			
Early	15.2	15.0	15.0
Late	15.4	15.0	14.0
Annual average	15.3	15.0	15.0
1952:			
1–100 eggs:			
Early	15.3	15.0	15.0
Late	16.0	16.0	17.0
Annual average	15.7	16.0	16.0
101+ eggs:			
Early	15.3	15.0	14.5
Late	15.9	15.5	14.5
Annual average	15.6	15.5	14.5
1953:			
1–100 eggs:			
Early	14.5	14.5	15.0
Late	15.9	15.5	16.0
Annual average	15.3	15.0	15.0
101+ eggs:			
Early	15.1	15.0	15.0
Late	16.1	15.5	15.0
Annual average	15.5	15.0	15.0
1954:			
1–100 eggs:			
Early	15.5	16.0	16.0
Late	16.6	16.5	16.5
Annual average	16.0	16.0	16.0
101+ eggs:			
Early	15.2	15.0	14.5
Late	15.2	15.0	14.0
Annual average	15.2	15.0	15.0
All years:			
1–100 eggs:			
Early	15.2	15.5	16.0
Late	16.0	16.0	16.0
Annual average	15.7	15.5	16.0
101+ eggs:			
Early	15.2	15.0	15.5
Late	15.7	15.0	15.0
Annual average	15.4	15.5	15.5

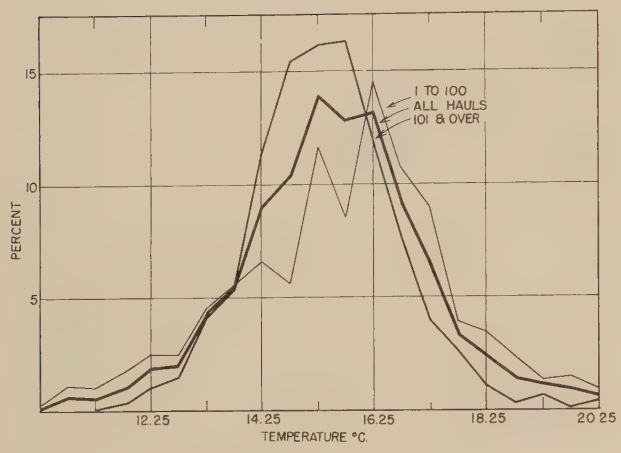


FIGURE 10.—Percentage of stations having jack mackerel eggs, grouped by 0.5° C. temperature intervals measured at 10-meter depth for stations with hauls of 1–100 eggs, with hauls of 101 eggs and more, and for all stations where eggs were taken.

All jack mackerel data were then combined for each year and the mean, median, and modal temperatures at 10 meters were computed (table 18). The mean and median temperatures for the 4 years are remarkably constant (15.5° C.) wit about 60 percent of the annual spawning occurrin within 1° of the median and mean. Less than 4 percent of all the stations occupied during th spawning season (February through July) ha temperatures within 1° of 15.5° C. (table 19 The constancy of annual temperature medians an means would indicate a sharp temperature opt mum for spawning were it not for the within-yea temperature shift. The within-year temperatur shift suggests that a physiological temperatur optimum for jack mackerel is a function of man environmental factors, such as condition of th fish and availability of food, to mention tw possibilities. Furthermore, if temperature is th controlling factor, spawning should occur more o less uniformly throughout the area having th optimum temperature. A temperature of 15.5° C is usually present in the waters off California o Baja California, but spawning occurs only durin spring and summer. This may indicate that th length of day has some regulatory effect o spawning.

TABLE 17.—*Summary: Distribution of temperatures at 10 meters, by season, at stations occupied, 1951–54*

[In 0.5° C. intervals]

Temperature	1951			1952			1953			1954			Total for all years	Percent of total
	Early	Late	Total	Early	Late	Total	Early	Late	Total	Early	Late	Total		
8.00–8.49	0	0	0	0	0	0	0	0	0	0	1	1	1	0.0
8.50–8.99	0	2	2	0	0	0	0	0	0	0	0	0	2	.0
9.00–9.49	0	0	0	1	0	1	3	1	4	0	1	1	6	.1
9.50–9.99	1	3	4	3	1	4	8	3	11	2	1	3	22	.4
10.00–10.49	2	8	10	5	11	16	7	4	11	2	6	8	45	.8
10.50–10.99	6	4	10	7	9	16	10	5	15	2	3	5	46	.8
11.00–11.49	12	10	22	6	20	26	18	9	27	7	6	13	88	1.6
11.50–11.99	13	7	20	5	14	19	37	5	42	13	6	19	100	1.8
12.00–12.49	18	9	27	19	21	40	52	12	64	19	11	30	161	2.9
12.50–12.99	13	7	20	31	26	57	59	21	80	35	14	49	206	3.7
13.00–13.49	36	15	51	35	31	66	59	21	80	46	16	62	259	4.7
13.50–13.99	50	19	69	49	20	69	78	37	115	64	21	85	338	6.2
14.00–14.49	50	33	83	59	27	86	72	42	114	93	30	123	406	7.4
14.50–14.99	42	30	72	70	31	101	75	36	111	94	29	123	407	7.4
15.00–15.49	71	49	120	62	46	108	60	54	114	94	43	137	479	8.7
15.50–15.99	66	51	117	61	35	96	65	41	106	96	39	135	454	8.3
16.00–16.49	63	52	115	53	50	103	35	50	85	61	65	126	429	7.8
16.50–16.99	53	45	98	43	50	93	29	38	67	43	54	97	355	6.5
17.00–17.49	47	43	90	30	57	87	21	43	64	31	56	87	328	6.0
17.50–17.99	36	49	85	24	39	63	21	39	60	15	39	54	262	4.8
18.00–18.49	21	45	66	7	41	48	6	33	39	18	55	73	226	4.1
18.50–18.99	9	40	49	8	33	41	8	28	36	11	36	47	173	3.1
19.00–19.49	3	30	33	4	30	34	7	29	36	11	18	29	132	2.4
19.50–19.99	6	29	35	12	18	30	2	16	18	5	37	42	125	2.3
20.00–20.49	0	18	18	5	13	18	1	12	13	0	31	31	80	1.4
20.50–20.99	1	21	22	5	17	22	2	9	11	1	11	12	67	1.2
21.00–21.49	2	10	12	3	15	18	4	8	12	1	10	11	53	.9
21.50–21.99	1	8	9	2	11	13	5	4	9	1	5	6	37	.6
22.00–22.49	2	8	10	1	6	7	0	5	5	0	5	5	27	.5
22.50–22.99	0	8	8	0	3	3	0	4	4	0	6	6	21	.3
23.00–23.49	0	6	6	1	6	7	0	0	0	0	3	3	16	.2
23.50–23.99	0	9	9	0	4	4	0	3	3	0	8	8	24	.4
24.00–24.49	0	8	8	0	6	6	0	1	1	0	0	0	15	.2
24.50–24.99	0	8	8	0	1	1	0	0	0	0	0	0	9	.1
25.00–25.49	0	2	2	0	0	0	0	1	1	0	0	0	3	.0
25.50–25.99	0	8	8	0	0	0	0	2	2	0	2	2	12	.2
26.00–26.49	0	8	8	0	0	0	0	1	1	0	1	1	10	.1
26.50 and over	0	15	15	0	0	0	0	2	2	0	0	0	17	.3
Total	624	717	1,341	611	692	1,303	744	619	1,363	765	669	1,434	5,441	99.9

ABLE 18.—*Annual mean, median, and modal temperatures at which spawning occurred, 1951–54*

[At 10 meters; in °C.]

Year	Median and mean temperature	Percent spawning within 1° of median	Mode
51	15.5	58	16.3
52	15.5	65	16.3
53	15.5	60	15.3
54	15.5	63	15.3

ABLE 19.—*Summary: Distribution of temperatures at 10 meters, at all stations occupied, February through July, 1951–54*

[In 0.5°C. intervals]

Temperature	1951		1952		1953		1954	
	Total	Percent	Total	Percent	Total	Percent	Total	Percent
00–8.49	0	0	0	0	0	0	1	0.10
50–8.99	0	0	0	0	0	0	0	0
00–9.49	0	0	1	0.12	4	0.44	1	.10
50–9.99	2	0.27	4	.49	10	1.10	3	.30
.00–10.49	7	.95	13	1.60	10	1.10	8	.81
.50–10.99	7	.95	11	1.35	15	1.65	5	.51
.00–11.49	10	1.36	20	2.46	25	2.74	12	1.21
.50–11.99	16	2.18	16	1.97	40	4.39	19	1.92
.00–12.49	20	2.72	34	4.18	61	6.70	25	2.53
.50–12.99	16	2.18	37	4.55	63	6.92	38	3.84
.00–13.49	35	4.76	50	6.15	61	6.70	51	5.16
.50–13.99	50	6.80	50	6.15	86	9.34	63	6.38
.00–14.49	61	8.30	60	7.37	79	8.66	92	9.30
.50–14.99	46	6.26	87	10.70	76	8.34	92	9.30
.00–15.49	77	10.49	75	9.23	87	9.55	102	10.31
.50–15.99	76	10.35	67	8.24	77	8.35	105	10.62
.00–16.49	80	10.90	76	9.35	49	5.38	97	9.81
.50–16.99	61	8.30	69	8.49	41	4.50	79	7.99
.00–17.49	48	6.53	53	6.52	43	4.72	62	6.27
.50–17.99	35	4.76	32	3.94	29	3.18	32	3.24
.00–18.49	36	4.90	18	2.22	15	1.65	35	3.54
.50–18.99	17	2.31	12	1.48	17	1.87	25	2.53
.00–19.49	5	.68	6	.74	11	1.21	16	1.62
.50–19.99	10	1.36	8	.98	3	.33	15	1.52
.00–20.49	5	.68	3	.37	4	.44	7	.71
.50–20.99	5	.68	3	.37	3	.33	2	.20
.00–21.49	3	.41	2	.25	1	.11	0	0
.50–21.99	1	.14	4	.49	1	.11	1	.10
.00–22.49	4	.54	1	.12	0	0	0	0
.50–22.99	1	.14	0	0	0	0	0	0
.00–23.49	0	0	1	.12	0	0	1	.10
.50–23.99	0	0	0	0	0	0	0	0
.00–24.49	1	.14	0	0	0	0	0	0
.50–24.99	0	0	0	0	0	0	0	0
.00–25.49	0	0	0	0	0	0	0	0

Turner (1948: p. 351) says, "The reproductive hythms of the female, as in the male, are influnced by numerous factors in the external environent as well as by physiologic factors conditioning he internal environment." Since little is known bout the internal factors governing the spawning f fishes, no comprehensive explanation for the ariation in the distribution of spawning jack nackerel can be given at this time. It is concluded that temperature is important, but not the ontrolling factor in spatial-temporal distribution f spawning jack mackerel.

SURVIVAL OF THE LARVAE

The method used by Ahlstrom (1954b) to determine the survival of larvae has been retained so that interspecific comparisons might more easily be made for fish occupying the area surveyed by the California Cooperative Oceanic Fisheries Investigations. All larvae of a species were withdrawn from a station sample and measured. The measurements are grouped into size classes and adjusted by the standard haul factor (p. 250). These standardized counts are integrated over time and space (p. 251) and adjusted for growth. The products are summed for the year to give an estimate of abundance of the size class. The decline in abundance of successively larger size classes provides an estimate of survival.

REGIONAL ESTIMATES OF ABUNDANCE OF LARVAE

The regional estimates of abundance by size class for jack mackerel larvae are given in table 20 for 1952, table 21 for 1953, and table 22 for 1954. These tables are summarized in tables 23 and 24, and the annual estimates of abundance and survival are given in table 25. It will be noted that the curves shown in figure 11 derived from this table are very similar, suggesting that the number of larvae surviving a 30-day period has

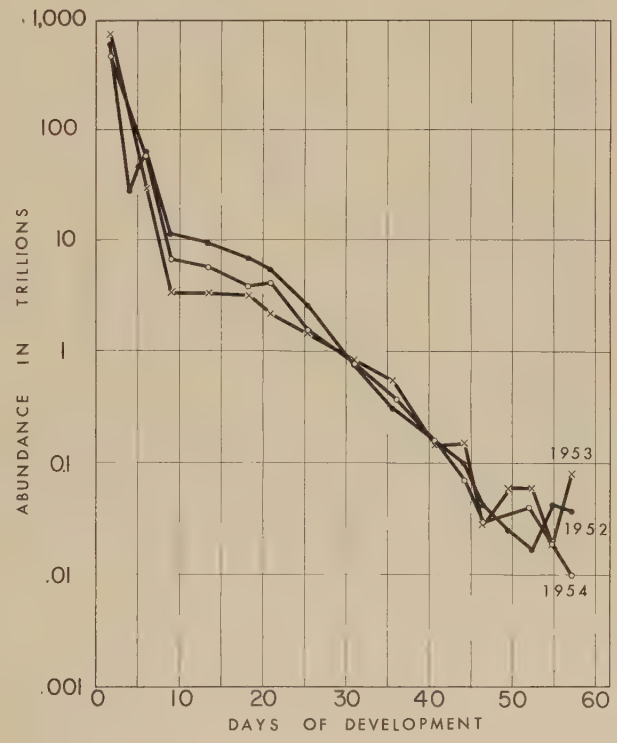


FIGURE 11.—Abundance curves of jack mackerel larvae to age 57 days, 1952–54.

been relatively constant. In 1952, of the 593 trillion eggs estimated to have been spawned, only 780 billion larvae are estimated to have survived at the end of 30 days. In 1953, 736 trillion eggs were estimated to have been spawned and 850 billion larvae are estimated to have survived, while in 1954, 462 trillion eggs were estimated to have been spawned with 830 billion larvae the estimated survivors at the end of the first month of life. This indicates an average survival (for the first month of life) of a little more than 1 larva per 1,000 eggs spawned.

TABLE 20.—*Regional distribution of jack mackerel larvae, by month and size class, 1952*

[In billions]

Area and month	2.0 mm.	2.5 mm.	3.0 mm.	3.5 mm.	4.0 mm.	4.5 mm.	5.0 mm.	5.75 mm.	6.75 mm.	7.75 mm.	8.75 mm.	9.75 mm.	10.75 mm.	11.75 mm.	12.75 mm.	13.75 mm.	14.75 mm.
Northern California (lines 40–77):																	
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	550	561	1,537	29	36	38	12	0	0	0	0	0	0	0	0	0	0
July	242	1,246	1,541	107	57	9	48	53	0	0	0	0	0	0	0	0	0
August	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	834	1,807	3,078	136	93	47	60	53	0	0	0	0	0	0	0	0	0
Southern California (lines 80–93):																	
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	311	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	2,156	3,068	2,334	468	258	261	103	33	0	0	0	0	0	0	0	0	0
April	134	1,287	2,916	1,026	2,337	1,351	1,429	409	33	12	0	0	0	0	0	0	0
May	3,130	8,654	8,116	841	582	183	145	17	0	0	0	0	8	0	0	0	0
June	1,640	2,727	5,355	778	1,206	926	766	252	71	15	0	0	8	0	0	0	0
July	285	2,145	2,591	1,098	391	704	668	553	235	95	7	0	0	25	0	0	0
August	307	761	1,250	24	30	0	0	38	9	0	12	14	0	0	17	0	0
September	480	503	140	7	23	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	8,443	19,375	22,717	4,242	4,827	3,425	3,111	1,302	348	122	19	14	16	25	17	0	0
Northern Baja California (lines 97–107):																	
January	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	363	2,825	3,599	1,361	425	205	15	22	0	0	0	0	0	0	0	0	0
April	7,089	6,478	3,749	383	960	292	551	325	82	28	0	0	0	0	0	0	0
May	3,374	6,506	6,944	577	7	168	359	70	28	11	0	8	0	0	0	0	0
June	83	510	2,930	629	505	284	254	204	147	83	16	0	5	0	0	0	0
July	1,962	3,612	7,523	2,103	1,241	1,238	379	277	50	36	103	58	0	0	0	0	37
August	27	1,284	2,365	283	189	77	51	16	9	0	0	0	6	0	0	0	0
September	0	68	151	73	264	205	18	0	0	0	0	0	0	0	0	0	0
October	0	15	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0
Total	12,898	21,324	27,261	5,409	3,591	2,469	1,641	914	316	158	119	66	11	0	0	0	37
Upper central Baja California (lines 110–120):																	
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	112	236	300	421	284	99	58	0	0	0	15	0	0	0	0
April	5,410	3,510	5,393	161	56	19	22	33	32	0	11	0	0	0	0	0	0
May	628	985	1,465	634	396	338	185	138	11	17	20	0	0	0	0	0	0
June	0	258	1,534	127	49	37	45	20	5	23	0	0	0	0	0	20	0
July	0	152	138	78	59	130	86	18	11	0	0	0	0	0	0	23	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	6,038	4,905	8,642	1,236	860	945	622	308	117	40	31	0	15	0	0	43	0
Lower central Baja California (lines 123–137):																	
March	0	49	48	8	34	29	0	0	0	0	0	0	0	0	0	0	0
April	0	448	1,179	65	0	0	0	0	0	0	0	22	0	0	0	0	0
May	83	25	441	50	45	21	45	6	0	0	0	0	0	0	0	0	0
June	0	122	97	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Total	83	644	1,765	123	79	50	45	10	0	0	0	22	0	0	0	0	0
Grand total	28,296	48,055	63,463	11,146	9,450	6,936	5,479	2,587	781	320	169	102	42	25	17	43	37

The slope of the abundance curve is not constant. Survival during the first 9 days is very low but after this initial period, it is better. The inconsistency in the estimates of larvae older than 9 days is most likely due to sample variation. These estimates are made from small numbers of observations and have therefore a large error associated with them.

Although these data are in some respects quite limited, they are comparable with the survival data collected by Sette (1943) for Atlantic mackerel and Ahlstrom (1954b) for Pacific sardine.

TABLE 21.—*Regional distribution of jack mackerel larvae, by month and size class, 1953*

[In billions]

Area and month	3.0 mm.	3.5 mm.	4.0 mm.	4.5 mm.	5.0 mm.	5.75 mm.	6.75 mm.	7.75 mm.	8.75 mm.	9.75 mm.	10.75 mm.	11.75 mm.	12.75 mm.	13.75 mm.	14.75 mm.
rthern California (lines 40–77):															
une	316	66	75	0	0	0	0	201	0	0	0	0	0	0	0
uly	175	51	40	40	15	17	10	0	0	0	0	0	0	0	0
ugust	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	555	117	115	40	15	17	10	201	0	0	0	0	0	0	0
thern California (lines 80–93):															
ebruary	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	2,846	113	11	11	0	4	50	0	0	0	0	0	18	0	0
pril	1,067	515	252	126	0	0	0	0	0	33	0	0	0	0	0
May	5,017	620	426	211	55	61	0	0	0	0	0	0	0	0	0
une	2,086	125	410	362	491	360	181	57	0	0	0	0	0	0	0
uly	883	114	51	315	27	261	68	0	20	22	0	0	30	0	59
ugust	32	0	0	0	36	19	0	0	0	0	0	0	0	0	0
eptember	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ctober	0	0	0	0	0	0	2	0	10	0	0	0	0	0	0
Total	11,931	1,487	1,150	1,025	609	705	301	57	30	55	0	0	48	0	59
rthern Baja California (lines 97–107):															
ebruary	2,712	274	161	17	0	0	0	41	0	0	0	0	0	0	0
March	996	223	697	971	409	69	69	11	0	10	0	0	0	0	0
pril	1,512	89	87	96	87	23	17	12	0	6	0	0	0	0	0
May	1,249	188	261	346	138	155	65	0	0	0	0	0	0	0	0
une	3,621	358	280	337	488	206	208	41	62	0	7	0	0	0	0
uly	213	22	70	8	18	20	6	13	0	0	0	0	0	0	0
ugust	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0
eptember	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ctober	151	0	64	10	46	18	20	0	6	0	0	0	0	0	0
Total	10,454	1,154	1,620	1,785	1,186	491	405	118	68	16	7	0	0	0	0
per central Baja California (lines 110–120):															
ebruary	183	0	0	0	11	0	0	0	0	0	0	0	0	0	0
March	680	58	145	155	267	186	15	69	0	6	0	14	0	0	0
pril	864	62	9	6	37	4	8	16	0	16	0	0	0	0	0
May	1,224	57	140	78	29	24	64	16	0	0	0	8	0	0	0
une	2,446	292	104	51	30	14	24	40	35	15	0	16	0	20	0
uly	0	0	0	0	0	0	25	0	0	0	0	23	13	0	0
ugust	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
eptember	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ctober	104	0	0	0	0	18	0	40	13	44	21	0	0	0	22
Total	5,501	478	398	290	374	246	136	181	48	81	21	61	13	20	22
wer central Baja California (lines 123–137):															
May	463	16	12	8	7	0	0	0	0	0	0	0	0	0	0
une	646	60	18	20	0	9	0	0	0	0	0	0	0	0	0
uly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ctober	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
Total	1,109	76	36	28	7	9	0	0	0	0	0	0	0	0	0
Grand total	29,550	3,312	3,319	3,168	2,191	1,468	852	557	146	152	28	61	61	20	81

TABLE 22.—*Regional distribution of jack mackerel larvae, by month and size class, 1954*

[In billions]

Month and area	3.0 mm.	3.5 mm.	4.0 mm.	4.5 mm.	5.0 mm.	5.75 mm.	6.75 mm.	7.75 mm.	8.75 mm.	9.75 mm.	10.75 mm.	11.75 mm.	12.75 mm.	13.75 mm.	14.7 mm
Northern California (lines 40–77):															
May	269	0	0	0	0	0	0	0	0	0	0	0	0	0	
June	2,061	210	150	141	108	17	0	0	0	0	0	0	0	0	
July	578	0	222	57	0	67	116	164	97	46	0	0	41	0	
August	0	0	0	0	0	0	53	0	0	0	0	0	0	0	
Total	2,908	210	372	198	108	84	169	164	97	46	0	0	41	0	
Southern California (lines 80–93):															
April	4,099	241	77	84	63	9	15	5	0	0	0	0	0	0	
May	6,549	525	130	59	31	29	18	0	0	0	0	0	0	0	
June	21,445	3,122	3,371	2,146	2,491	1,034	478	222	22	13	0	0	0	0	
July	455	0	0	0	0	37	16	0	10	0	0	0	0	0	
August	39	4	5	15	10	5	1	0	4	0	0	0	0	0	
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
October	133	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	32,720	3,892	3,583	2,304	2,595	1,114	528	227	36	13	0	0	0	0	
Northern Baja California (lines 97–107):															
February	175	0	0	0	0	0	0	0	0	0	0	0	0	0	
March	2,424	185	97	371	555	85	9	6	0	0	0	0	0	0	
April	5,022	707	353	456	278	88	45	30	10	0	0	0	0	0	
May	4,566	428	203	102	78	38	21	16	21	0	26	0	0	0	
June	2,704	301	303	79	194	103	42	6	0	0	0	0	0	0	
July	741	14	17	0	0	6	7	0	0	0	0	0	0	0	
August	61	31	18	0	9	11	0	0	0	0	5	0	0	0	
Total	15,693	1,666	991	1,008	1,114	331	124	58	31	0	31	0	0	0	
Upper central Baja California (lines 110–120):															
February	820	37	15	22	0	0	0	0	0	0	0	0	0	0	
March	2,437	214	321	139	84	5	0	0	0	0	0	0	0	0	
April	1,058	76	235	64	4	0	3	0	0	0	0	0	0	0	
May	1,312	373	125	39	139	0	4	0	0	0	0	0	0	0	
June	1,710	162	96	60	92	12	0	35	0	0	0	0	0	0	
July	27	39	0	0	0	0	0	0	0	0	0	0	0	0	
Total	7,364	901	792	324	319	17	7	35	0	0	0	0	0	0	
Lower central Baja California (lines 123–137):															
January	198	17	10	0	0	0	0	0	0	0	0	0	0	0	
February	0	9	0	0	0	0	0	0	0	0	0	0	0	0	
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
April	270	19	0	0	6	0	0	0	0	13	0	0	0	0	
May	70	0	0	0	8	2	5	0	0	0	0	0	0	0	
June	74	10	0	0	0	0	0	0	0	0	0	0	0	0	
July	0	18	0	0	0	0	0	0	0	0	0	0	0	0	
August	0	17	0	0	0	0	0	0	0	0	0	0	0	0	
Total	612	90	10	0	14	2	5	0	0	13	0	0	0	0	
Grand total	59,297	6,759	5,748	3,834	4,150	1,518	833	484	164	72	31	0	41	0	

TABLE 23.—*Regional distribution of jack mackerel larvae, by size class, 1952–54*

[In billions]

Year and region	3.0 mm.	3.5 mm.	4.0 mm.	4.5 mm.	5.0 mm.	5.75 mm.	6.75 mm.	7.75 mm.	8.75 mm.	9.75 mm.	10.75 mm.	11.75 mm.	12.75 mm.	13.75 mm.	14.75 mm
1952:															
Northern California (lines 40–77)	3,078	136	93	47	60	53	0	0	0	0	0	0	0	0	
Southern California (lines 80–93)	22,717	4,242	4,827	3,425	3,111	1,302	348	122	19	14	16	25	17	0	
Northern Baja California (lines 97–107)	27,261	5,409	3,591	2,469	1,641	914	316	157	119	66	11	0	0	0	3
Upper central Baja California (lines 110–120)	8,642	1,236	860	945	622	308	117	40	31	0	15	0	0	43	
Lower central Baja California (lines 123–137)	1,765	123	79	50	45	10	0	0	0	22	0	0	0	0	
Total	63,463	11,146	9,450	6,936	5,479	2,587	781	319	169	102	42	25	17	43	3
1953:															
Northern California (lines 40–77)	555	117	115	40	15	17	10	201	0	0	0	0	0	0	
Southern California (lines 80–93)	11,931	1,487	1,150	1,025	609	705	301	57	30	55	0	0	48	0	8
Northern Baja California (lines 97–107)	10,454	1,154	1,620	1,785	1,186	491	405	118	68	16	7	0	0	0	
Upper central Baja California (lines 110–120)	5,501	478	398	290	374	246	136	181	48	81	21	61	13	20	2
Lower central Baja California (lines 123–137)	1,109	76	36	28	7	9	0	0	0	0	0	0	0	0	
Total	29,550	3,312	3,319	3,168	2,191	1,468	852	557	146	152	28	61	61	20	8
1954:															
Northern California (lines 40–77)	2,908	210	372	198	108	84	169	164	97	46	0	0	41	0	
Southern California (lines 80–93)	32,720	3,892	3,583	2,304	2,595	1,114	528	227	36	13	0	0	0	0	
Northern Baja California (lines 97–107)	15,693	1,666	991	1,008	1,114	331	124	58	31	0	31	0	0	0	1
Upper central Baja California (lines 110–120)	7,364	901	792	324	319	17	7	35	0	0	0	0	0	0	
Lower central Baja California (lines 123–137)	612	90	10	0	14	2	5	0	0	13	0	0	0	0	
Total	59,297	6,759	5,748	3,834	4,150	1,548	833	484	164	72	31	0	41	0	1

TABLE 24.—*Percentage of each size class of jack mackerel larvae, occurring in each region, 1952–54*

Year and region	3.0 mm.	3.5 mm.	4.0 mm.	4.5 mm.	5.0 mm.	5.75 mm.	6.75 mm.	7.75 mm.	8.75 mm.	9.75 mm.	10.75 mm.	11.75 mm.	12.75 mm.	13.75 mm.	14.75 mm.
1952:															
Northern California (lines 40–77)	4.9	1.2	1.0	0.7	1.1	2.0	0	0	0	0	0	0	0	0	0
Southern California (lines 80–93)	35.8	38.0	50.9	49.4	56.7	50.2	44.8	38.1	10.9	13.7	39.0	100.0	100.0	0	0
Northern Baja California (lines 97–107)	43.1	48.6	37.8	35.6	30.0	35.2	40.5	49.4	71.0	65.1	26.7	0	0	0	100.0
Upper central Baja California (lines 110–120)	13.6	11.1	9.1	13.6	11.3	11.8	14.7	12.5	18.1	0	34.3	0	0	100.0	0
Lower central Baja California (lines 123–137)	2.8	1.1	0.8	0.7	0.8	0.4	0	0	0	21.2	0	0	0	0	0
Total	100.2	100.0	99.6	100.0	99.9	99.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1953:															
Northern California (lines 40–77)	1.8	3.5	3.5	1.3	0.7	1.1	1.2	36.1	0	0	0	0	0	0	0
Southern California (lines 80–93)	40.4	44.8	34.6	32.4	27.8	48.0	35.4	10.3	20.4	35.9	0	0	79.4	0	72.6
Northern Baja California (lines 97–107)	35.4	34.9	48.8	56.3	54.1	33.4	47.5	21.1	46.5	10.3	26.3	0	0	0	0
Upper central Baja California (lines 110–120)	18.6	14.4	11.9	9.2	17.0	16.8	15.9	32.5	32.9	53.8	73.7	100.0	20.6	100.0	27.4
Lower central Baja California (lines 123–137)	3.8	2.3	1.1	0.9	0.3	0.6	0	0	0	0	0	0	0	0	0
Total	100.0	99.9	99.9	100.1	99.9	99.9	100.0	100.0	99.8	100.0	100.0	100.0	100.0	100.0	100.0
1954:															
Northern California (lines 40–77)	4.9	3.1	6.5	5.2	2.6	5.4	20.3	34.1	59.2	64.5	0	0	100.0	0	0
Southern California (lines 80–93)	55.2	57.4	62.4	60.1	62.6	72.1	63.4	47.0	22.0	17.7	0	0	0	0	0
Northern Baja California (lines 97–107)	26.4	24.6	17.3	26.2	26.9	21.4	14.9	11.7	18.8	0	100.0	0	0	0	100.0
Upper central Baja California (lines 110–120)	12.4	13.3	13.8	8.4	7.7	1.0	0.7	7.2	0	0	0	0	0	0	0
Lower central Baja California (lines 123–137)	1.0	1.3	0.2	0	0.3	0.1	0.6	0	0	17.8	0	0	0	0	0
Total	99.9	99.7	100.2	99.9	100.1	100.0	99.9	100.0	100.0	100.0	100.0	0	100.0	0	100.0

TABLE 25.—*Annual estimates of abundance and survival of jack mackerel eggs and larvae, 1952–54*

[In billions]

Category	Duration (days)	Average age (days)	Size range (mm.)	1952		1953		1954	
				Abundance	Survival per 100,000 eggs	Abundance	Survival per 100,000 eggs	Abundance	Survival per 100,000 eggs
Eggs	3.6	1.8		593,100		736,100		462,300	
Larvae:									
2.0 mm	1.0	4.1	1.90–2.25	28,300	4,711				
2.5 mm	1.0	5.1	2.26–2.75	48,100	8,109				
3.0 mm	1.0	6.1	2.76–3.25	63,500	10,706	29,500	4,007	59,300	12,827
3.5 mm	4.8	9.0	3.26–3.75	11,100	1,871	3,300	448	6,800	1,470
4.0 mm	4.2	13.5	3.76–4.25	9,400	1,548	3,300	448	5,700	1,232
4.5 mm	3.7	17.4	4.26–4.75	6,900	1,163	3,200	434	3,800	821
5.0 mm	3.3	21.0	4.76–5.25	5,500	927	2,200	298	4,100	886
5.75 mm	5.9	25.5	5.26–6.25	2,600	438	1,500	203	1,500	324
6.75 mm	5.0	31.0	6.26–7.25	780	131	850	115	830	179
7.75 mm	4.3	35.7	7.26–8.25	320	53	560	76	480	97
8.75 mm	3.8	39.4	8.26–9.25	170	28	150	20	160	34
9.75 mm	3.5	43.3	9.26–10.25	100	16	150	20	71	15
10.75 mm	3.1	46.7	10.26–11.25	42	7	28	3	30	6
11.75 mm	2.9	49.7	11.26–12.25	25	4	60	8		
12.75 mm	2.6	52.4	12.26–13.25	17	2	60	8	41	8
13.75 mm	2.4	54.9	13.26–14.25	43	7	20	2		
14.75 mm	2.3	57.2	14.26–15.25	37	6	81	11	10	2

GROWTH RATE OF LARVAE

The growth rate of jack mackerel larvae was obtained by direct observation of material taken from station 70 on line 97 (97.70) during March of 1957 (Farris, 1959). Eggs were taken from the sea with a plankton net, sorted according to developmental stage, placed in jars of fresh sea water, and observed daily until they hatched. After hatching the larvae were measured daily until they died. No attempt was made to feed the fish. The measurements were averaged daily and plotted as log average length against days (fig. 12). Such a plot suggested that growth during the first 3 days was more rapid than for the next 4 days. The yolk sac was absorbed and the eyes became pigmented on the sixth day of larval life. The growth rates for the first 3 days (section A) and for the following 4 days (section B) were then compared by regression analysis (table 26), where X=days past hatching, Y=length in millimeters, log $Y=a+bX$, s_b=standard deviation of slope, and $s_{y/x}$=standard deviation of sample points

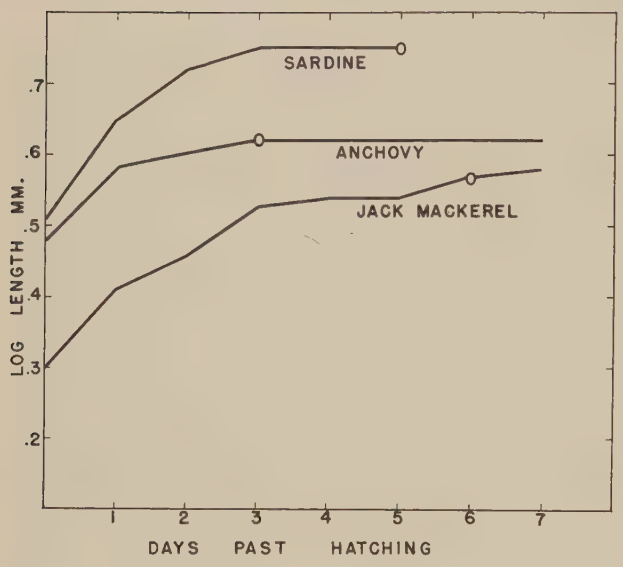


FIGURE 12.—Growth curves of jack mackerel, Pacific sardine, and northern anchovy. (Open circles indicate complete absorption of the yolk.)

from the line. The comparison of the two slopes indicated that the initial relative growth rate is about five times that of the later relative growth rate.

TABLE 26.—*Regression statistics for the relative growth rate of jack mackerel larvae*

	a	b	s_b	$s_{y/x}$	$\bar{X}$	$\bar{Y}$
Section A: days 1 through 3	0.328	0.067	0.0091	0.0616	1.3	0.614
Section B: days 4 through 8	.486	.013	.0017	.0184	3.1	.687

The relative growth rates of the other two species (Pacific sardine, *Sardinops caerulea*, and northern anchovy, *Engraulis mordax*) illustrated in figure 12 are similar to the growth rate shown for jack mackerel. In addition, the relative growth rate of the sardine as determined by direct observation (b=0.018) is in good agreement with the relative growth rate (b=0.019) determined by Ahlstrom (1954b) using an indirect method (Farris, 1959: p. 33). Ahlstrom, working with preserved material, was able to follow length-frequency modes through time.

Although growth has been described by two log curves instead of one, either would have served as well for estimating survival. The abundance of a size class is given by the following equation:

$$C=\sum_{i=1}^{n}\frac{c_i' w_i t_i}{d_i}$$

where

C=estimate of total abundance of larvae of size class

c_i'=standard number of larvae belonging to the size class at the ith station

w_i=area factor proportional to area of the ith station

t_i=time factor equal to one-half the time from preceding ocupancy plus one-half the time to succeeding occupancy

d_i=duration of size category in days, i.e., the number of days used by larvae to grow from the lower-size boundary to the upper-size boundary of the size class

n=number of stations considered.

The effects of 1- and 2-phase growth on mortality estimates were compared by recomputing estimates of abundance for sardines given by Ahlstrom (1954b: p. 133). In recomputing abundance of yolk-sac larvae, the formula used was—Duration of size category (days)=

$$\frac{\log l''-\log l'}{0.081},$$

where 0.081 is the log increase in length per day of the larvae, l' is the lower boundary of the size-class interval, and l'' is the upper boundary of the size-class interval. The duration of size category for the remaining size categories of larvae is given by—

$$\frac{\log l''-\log l'}{0.018}.$$

The results of the recomputation are given in table 27 under the heading "double phase," and may be compared with Ahlstrom's figures. The slight differences in average age for given size may be due to shrinkage of the larvae upon preservation in formalin.

Since relative growth rates derived from laboratory observations on the first 5 days in the life of a sardine could be extrapolated and reconciled

ith field observations, it was assumed that the xtrapolation could be made for jack mackerel, too. An analysis of successive length–frequency iagrams has not been used because the time nterval between successive cruises is too great or the estimation of a rapid growth rate. Secndly, any changes in the survival of larvae etween cruises would influence the length freuencies; hence the changes would alter the stimation of the growth parameter and thereby lter the estimates of annual survival. A growth ate derived from direct observation has the dvantage of being independent of variation in urvival.

ABLE 27.—*Estimates of abundance of young sardine, using single phase and double phase growth curves, 1950*

[Single phase after Ahlstrom (1954b)]

Category	Size range (mm.)	Duration (days)	Average age (days)	Estimated abundance
ngle phase:				
Egg		3.0	1.5	285,676
Yolk-sac larvae	2.26- 4.25	3.5	4.8	11,850
Larvae:				
4.75 mm	4.26- 5.25	4.8	8.9	10,778
5.75 mm	5.26- 6.25	3.9	13.2	5,590
6.75 mm	6.26- 7.25	3.3	16.8	6,197
7.75 mm	7.26- 8.25	2.9	20.0	5,931
8.75 mm	8.26- 9.25	2.6	22.7	4,834
9.75 mm	9.26-10.25	2.3	25.1	3,738
10.75 mm	10.26-11.25	2.1	27.3	2,880
uble phase:				
Egg		3.0	1.5	285,676
Yolk-sac larvae:				
3.25 mm	2.26- 4.25	1.9	3.9	21,829
4.75 mm	4.26- 5.25	5.1	7.5	10,144
Larvae:				
5.75 mm	5.26- 6.25	4.2	12.1	5,191
6.75 mm	6.26- 7.25	3.5	15.9	5,843
7.75 mm	7.26- 8.25	3.1	19.2	5,548
8.75 mm	8.26- 9.25	2.7	22.1	4,655
9.75 mm	9.26-10.25	2.4	24.7	3,582
10.75 mm	10.26-11.25	2.2	27.0	2,749

The regression statistics of section A (table 26) ere used to estimate the duration of the various ze categories of jack mackerel through the 0-mm. size class and the regression statistics f section B for all size classes thereafter. The uration of the size category (in days) through ne 3.0-mm. size category is given by—

$$\frac{\log l'' - \log l'}{0.067},$$

here l'' is the upper boundary of the size class, nd l' is the lower boundary.

The duration of the size category (in days) for ll remaining size categories is given by—

$$\frac{\log l'' - \log l'}{0.013}.$$

The average age for any size category is given by summing the duration of size class for shorter size classes and adding one-half the duration of the size category under consideration. For example, the average age of the 4.5-mm. size category is obtained by summing the durations for categories, eggs through 4.0 (15.6) and adding one half of 3.7. The average age is 17.4 days.

The coincidence of the absorption of the yolk-sac and the inflection of the survival curve is tentatively interpreted as follows:

Basic mortality rates of pelagic fish eggs and yolk-sac larvae are high owing to factors intrinsic to the eggs and inherent in the species; most of those which are unfit have died before absorbing their yolk or die shortly thereafter; the survivors beyond the critical stage now survive at a higher rate because they have successfully negotiated the change in nutrition (i.e., from yolk to copepod eggs and nauplii). A more comprehensive exposition of this hypothesis is given by Farris (1960).

SOURCES OF ERROR AND BIAS IN SAMPLING LARVAE

In the section on sources of error in egg sampling, some of the more obvious sources of error and bias were examined. These same sources of error were examined in sampling procedures for larvae. In addition, the avoidance of the net by the larvae might be added as a source of error.

RETENTION OF LARVAE BY THE NETS

Incomplete retention by the net of some small size classes of larvae becomes a serious problem. Estimates of abundance were made for the 2.0- and 2.5-mm. size classes of larvae in 1952 (table 25). These estimates are lower than the estimated abundance of the 3.0-mm. size-class larvae, indicating that the smaller size classes were undersampled. Larvae less than 3.0 mm. in length, meeting the mesh head on, are able to pass through and do not appear in our collections in proportion to their true abundance. Estimates for these size classes were not made in 1953 and 1954.

Figure 4, from Ahlstrom and Ball (1954) suggests that the head depth may be 10 to 20 percent greater than the body depth at the pectoral. If this is so, the maximum depth of the 3.0-mm. larvae is greater than the maximum mesh opening of the sampling net (0.55 mm. after shrinking

and 0.7 mm. before shrinking). As the larvae grow longer, their bodies grow increasingly deep and they are therefore retained within the sampling net. Evidence that larvae 3.0 mm. and longer would be retained once they are in the plankton net is given in table 28.

TABLE 28.—*Standard length and body depth at pectoral of jack mackerel larvae*

[Measurements in millimeters]

Average standard length	Average depth at pectoral
2.8 [1]	0.46 [1]
3.2	0.62
3.8	0.82
4.2	1.03
4.8	1.23

[1] Data from Ahlstom and Ball (1954, p. 215–216).

SAMPLING OF THE VERTICAL RANGE

The vertical distribution of larvae was examined for both the total range and quantitative diurnal differences in abundance at different depths. The data (table 29, after Ahlstrom, 1959: p. 119) indicate that almost all the larvae were found above 100 meters and that no larvae were found below 140 meters. Since net hauls are routinel made from a 140-meters depth, the net passe through the entire water column which can b expected to contain jack mackerel larvae.

The possibility of quantitative day-night differ ences (because of diurnal vertical migration) wa analyzed by examining the vertical distribution o samples taken during the day and at night. Thes comparable day-night series were completed fo several stations. The 2-, 8-, and 19-meter strat contain proportionally more larvae when sample in the day than at night. The data indicate tha there may be some slight tendency for the larva to migrate to the surface during the day; however it is more likely that there was a change in th water being sampled at station 94.80 (5403) between the day and night series. Both sardin and anchovy larvae are known to be distributed somewhat deeper in the daytime (negative photo taxis) than at night (Ahlstrom, 1959), as are many species of plankton organisms, so that a positive phototaxis would need to be better documented than is possible from our data. No definite diurnal variation in vertical distribution is evi denced.

TABLE 29.—*Standard number of jack mackerel larvae taken in day and night hauls, by depths*

[Stations in parentheses; after Ahlstrom, 1959]

Depth range (m.)	Average depth (m.)	Day hauls							Night hauls						
		Cruise 4106 (94.37)	Cruise 4106 (94.47)	Cruise 5206 (90.28)	Cruise 5305 (93.50)	Cruise 5403 (94.80)	Total larvae taken	Percent of total	Cruise 4106 (94.37)	Cruise 4106 (94.47)	Cruise 5206 (90.28)	Cruise 5305 (93.50)	Cruise 5403 (94.80)	Total larvae taken	Percent of total
2–3	2	0	0	0	0	92	92	42.8	0	0	12	0	26	38	42.7
6–10	8	0	0	2	0	86	88	40.9	0	0	13	4	0	17	19.1
16–21	19	0	0	0	0	24	24	11.2	0	4	*0	0	5	9	10.1
24–31	28	0	0	*0	0	2	2	.9	*0	*3	0	0	7	10	11.2
33–45	41	*1	*0	0	2	2	5	2.3	0	0	1	0	6	7	7.9
46–60	56	0	0	0	0	2	2	.9	0	0	0	0	8	8	9.0
63–79	72	0	0	0	0	2	2	.9	0	0	0	0	0	0	0
92–112	105	0	0	0	*0	*0	0	0	0	0	0	*0	*0	0	0
127–150	138	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200–239	215	0	0	0	0	0	0	0	0	0	0	0	0	0	0
276–291	285	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		1	0	2	2	210	215	99.9	0	7	26	4	52	89	100.0

*Region of the thermocline.

VARIABLE DISTRIBUTION OF LARVAE

The difficulties in assessing the variability of these estimates have previously been discussed in the section on sources of error in sampling eggs. Since the proper statistical model is not known at this time, no good estimate of error can be given. It was shown in the case of eggs that for a large number of interpolations in space and time the error tended toward zero. The error of the esti mates of abundance for the larvae is probably as great as the error of the estimates for egg abund ance, and very likely it is even greater. This may be particularly true for the estimates of abundance of the older size categories which are based on fewer than 10 observations.

SAMPLING OF THE HORIZONTAL RANGE

It was shown that incomplete sampling of the tire range of jack mackerel spawning introduced error of at least 21 percent of the estimated total g population. This error appears to be reduced the estimates of larvae. A very small propor- n of the 30-day and older larvae is taken sea- rd of stations 90 (tables 30, 31, and 32). These bles were constructed using the standard numbers jack mackerel larvae (6.75 mm size-class) for all tions sampled during the year. The data re grouped by 2-month intervals about selected mpling lines and further grouped to reflect the shore-inshore distribution of the larvae as was ne with the eggs (see p. 253). The data seem to dicate that almost all the 30-day-old larvae are be found in an area bounded by line 80 on the rth, line 110 on the south, stations 90 on the st, and the coast on the east. Some larvae are nd both to the north and south of the main ea. This area is far more restricted than that nibited by the distribution of the eggs (see ove).

BLE 30.—*Relative north-south, inshore-offshore distribu- ion of 6.75-mm. (30-day old) jack mackerel larvae, by -month intervals, 1952*

[Standard haul totals]

Lines	Stations			Total	Percent
	100-seaward	90–70	60-shore		
ruary-March:					
	(1)	(1)	(1)	(1)	(1)
	(1)	(1)	(1)	(1)	(1)
	0	0	0	0	0
	(1)	0	0	0	0
0	(1)	0	0	0	0
0	(1)	2.7	8.3	11.0	100.0
0	(1)	0	0	0	0
Total	0	2.7	8.3	11.0	100.0
Percent	0	24.5	75.5	100.0	
l-May:					
	(1)	0	0	0	0
	(1)	0	0	0	0
	0	0	0	0	0
	0	9.4	0	9.4	16.8
0	0	19.2	8.2	27.4	48.9
0	(1)	9.0	10.2	19.2	34.3
0	(1)	0	0	0	0
Total	0	37.6	18.4	56.0	100.0
Percent	0	67.2	32.8	100.0	
e-July:					
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	42.4	53.3	95.7	45.4
0	0	47.1	54.9	102.0	48.4
0	(1)	3.6	5.9	9.5	4.5
0	(1)	3.1	0	3.1	1.5
Total	0	96.2	114.1	210.3	99.8
Percent	0	45.7	54.3	100.0	

Region not occupied.

TABLE 31.—*Relative north-south, inshore-offshore distribution of 6.75-mm. (30-day old) jack mackerel larvae, by 2-month intervals, 1953*

[Standard haul totals]

Lines	Stations			Total	Percent
	100-seaward	90–70	60-shore		
February-March:					
60	(1)	(1)	(1)	(1)	(1)
70	(1)	(1)	(1)	(1)	(1)
80	4.9	0	0	4.9	16.2
90	(1)	0	3.8	3.8	12.5
100	(1)	8.4	8.1	16.5	54.5
110	(1)	0	5.1	5.1	16.8
120	(1)	0	0	0	0
Total	4.9	8.4	17.0	30.3	100.0
Percent	16.2	27.8	56.0	100.0	
April-May:					
60	0	0	0	0	0
70	(1)	0	0	0	0
80	0	0	0	0	0
90	0	0	0	0	0
100	(1)	5.9	18.4	24.3	31.6
110	(1)	0	52.6	52.6	68.5
120	(1)	0	0	0	0
Total	0	5.9	71.0	76.9	100.1
Percent	0	7.7	92.3	100.0	
June-July:					
60	(1)	0	0	0	0
70	0	0	0	0	0
80	0	12.1	3.0	15.1	6.9
90	(1)	35.2	36.8	72.0	32.9
100	0	32.6	18.6	51.2	23.3
110	(1)	11.8	58.9	70.7	32.2
120	(1)	0	10.3	10.3	4.7
Total	0	91.7	127.6	219.3	100.0
Percent	0	41.8	58.2	100.0	

[1] Region not occupied.

There are several possible explanations for the relatively restricted distribution of jack mackerel larvae. Four interactions of ocean current and fish survival are discussed as possible explanations of the observed distribution.

Uniform current flow, differential survival.—In this model, it is assumed that the southerly flowing California Current has a uniform velocity, i.e., it has no eddies or countercurrents, and the larvae have a differential survival. The eggs spawned in some part of the Current will survive at a much higher rate over those deposited in other parts. Under the conditions of this model, the older larvae (survivors) would occur in regions south of the one in which they were spawned, never north of the spawning region. If the current, though of uniform velocity, is very slow, the southward displacement will be slight and therefore very hard to measure.

Uniform current flow, uniform survival.—If the California Current flowing south contained larvae which survived equally well in any part of the current, one would expect the older larvae to

TABLE 32.—*Relative north-south, inshore-offshore distribution of 6.75-mm. (30-day old) jack mackerel larvae, by 2-month intervals, 1954*

[Standard haul totals]

Lines	Stations			Total	Percent
	100-seaward	90–70	60-shore		
February-March:					
60	(1)	(1)	(1)	(1)	(1)
70	(1)	(1)	(1)	(1)	(1)
80	0	0	0	0	0
90	(1)	0	0	0	0
100	(1)	5.3	0	5.3	100.0
110	(1)	0	0	0	0
120	(1)	0	0	0	0
Total	0	5.3	0	5.3	100.0
Percent	0	100.0	0	100.0	
April-May:					
60	0	0	0	0	0
70	(1)	0	0	0	0
80	(1)	4.5	0	4.5	8.4
90	(1)	3.0	6.2	9.2	17.1
100	0	3.2	8.7	11.9	22.1
110	(1)	5.9	15.8	21.7	40.1
120	(1)	0	6.6	6.6	12.3
Total	0	16.6	37.3	53.9	100.0
Percent	0	30.8	69.2	100.0	
June-July:					
60	0	3.0	0	3.0	1.5
70	(1)	10.5	0	10.5	5.1
80	2.8	7.7	49.8	60.3	29.5
90	(1)	54.8	56.0	110.8	54.2
100	(1)	2.9	13.8	16.7	8.2
110	(1)	0	3.1	3.1	1.5
120	(1)	0	0	0	0
Total	2.8	78.9	122.7	204.4	100.0
Percent	1.4	38.5	60.1	100.0	

[1] Region not occupied.

occur always to the south of the spawning area. If one considers the special conditions of low current velocity and high larval mortality, a sampling problem becomes apparent. Consider: A small subarea *X* on the periphery of the spawning area contains a thousand eggs. At the end of a month, one larva has survived. Subarea *Y* in the center of the spawning area contains a million eggs. Under conditions of uniform survival a thousand larvae would survive at the end of a month. The sampler has a much better chance of obtaining larvae from subarea *Y* than from subarea *X*. The failure in obtaining month-old larvae from peripheral areas would lead to a conclusion of better survival in the center of the spawning area, though in fact, survival was uniform over the entire area.

Differential current flow, uniform survival.— Under conditions of this model, the California Current would have an average transport to the south, but some parts of the water would move faster than others, and eddy currents would be present. The larvae, although surviving at a uniform rate, would not appear to do so becau of the postulated concentrating mechanisms. high proportion of the larvae would be found the eddies.

Differential current flow, differential survival. Using this model, it is virtually impossible predict the distribution of the older larvae, that distribution depends on the special conditio of the current and survival.

Since the average flow, as determined fro dynamic topography of the California Current, slow (about 0.2 knot) and since it contains wat flowing both slower and faster accompanied b eddies, no definite conclusion may be reache concerning differential survival, although surviv appears to be better in some regions (table 33).

TABLE 33.—*Annual regional summary of distribution jack mackerel eggs and month-old larvae, 1952–54*

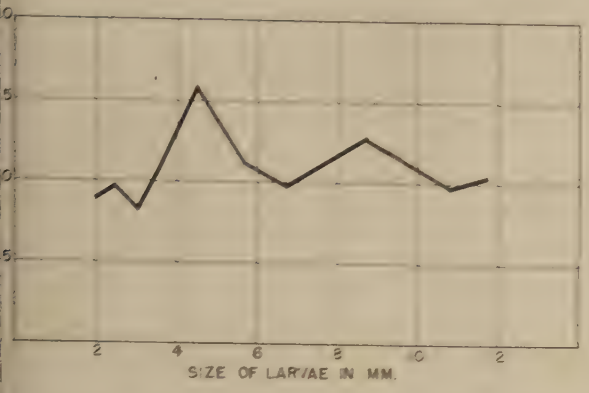
[Survival at the end of 1 month is given for each region]

Year and region	Eggs (billions)	Percent of total	Larvae [1] (billions)	Percent of total	Surviv per 100,0 eggs
1952:					
1	15,685	2.64	0	0	0
2	246,940	41.64	348	44.8	1.
3	257,418	43.40	316	40.5	1.
4	68,902	11.63	115	14.7	1.
5	4,137	0.69	0	0	0
6	0	0	0	0	0
Total	593,082	100.00	779	100.0	
1953:					
1	9,653	1.31	10	1.2	1.
2	185,095	25.14	301	35.4	1.
3	353,517	48.02	405	47.5	1.
4	176,573	23.99	136	15.9	.
5	11,294	1.53	0	0	0
6					
Total	736,132	99.99	852	100.0	
1954:					
1	31,116	6.73	169	20.3	5.
2	177,141	38.31	527	63.4	3.
3	185,765	40.18	124	14.9	.
4	49,228	10.65	6	.7	.
5	19,088	4.13	5	.6	.
Total	462,338	100.00	831	99.9	

[1] 6.75-mm. size class; estimated to be 1 month old.

AVOIDANCE OF NET

When Ahlstrom (1954b) computed the mortality of sardines, he found that a correction was necessary to account for the larvae which dodged the sampling net. He demonstrated dodging in a relative way by examining the ratio of average number of sardine larvae per night haul (when presumably the larvae cannot see the net) to the average number of larvae per day haul. When he computed the night/day ratio for each size class he found that the ratio increased with size. The



URE 13.—Ratio of the average number of jack mackerel rvae per night haul to the average number taken per ay (N/D), by size class, 1952–54.

plication was that as the larvae grew larger and onger they were better able to dodge the net. s increase in ratio with size is true not only of sardine, but also of the anchovy, the hake, the ific mackerel, et cetera (Ahlstrom, personal mmunication; Bridger, 1956).

t is, indeed, surprising to find that jack mack- do not behave in this manner. All jack ckerel data for 3 years have been combined in re 13. The N/D ratio for the 7.75-mm. size s has been deleted because one of the samples, ch was unusually large, prevented comparison his size class with the other size classes. A t-squares line has been fitted to the data $a+bX$, where X=size in millimeters and N/D ratio. The regression statistics are 1.06; b=0.006; $s_{y/x}$=0.196; $\overline{X}$=6.0; $\overline{Y}$=1.10; 0.057.

he slope of the regression is not significantly erent from zero. The interpretation placed these data is that jack mackerel do not dodge net despite their apparent ability to do so. eyes are pigmented and presumably func- al about the time the yolk is absorbed (at roximately 3.5 mm.), and larvae at yolk-sac orption are capable of movement. Ahlstrom rsonal communication) believes that jack ckerel larvae can swim as well as the sardine rae.

SUMMARY

he distribution and abundance of jack mack- eggs is described for 4 years, 1951 through 4. The early survival of jack mackerel larvae escribed for 1952, 1953, and 1954. The data were obtained from monthly cruises during which an average of 150 stations was occupied.

Jack mackerel spawned in an area bounded by the 26th parallel on the south, the 45th parallel on the north, the west coast of North America on the east, and the 150th meridian on the west. Most of the spawning occurred in a more restricted area, the boundaries of which varied from year to year. Eggs were mainly confined to the upper 40 meters of water.

Spawning usually began in February, reached a peak in May, and ceased by October. The peak of spawning in 1951, which occurred in March, is considered abnormally early.

The temperature coefficient for the rate of egg development was derived by a regression of log hours of development on temperature in degrees centigrade. Jack mackerel eggs kept under controlled temperature conditions (in an incubator) hatched at the time predicted by the derived temperature coefficient.

The estimates of egg abundance for 1951, 1952, 1953, and 1954 are 8.7×10^{14}, 5.9×10^{14}, 7.4×10^{14}, and 4.6×10^{14}, respectively.

The survival at the end of a 30-day period for 1952, 1953, and 1954 was 131, 112, and 179 larvae per 100,000 eggs spawned, respectively. The variation was considered insignificant. An increase in survival rate during the second week of larval life was noted.

The relative growth rate of jack mackerel larvae was approximated from observations on laboratory populations. The relative growth during the first 3 days is more rapid by a factor of 5 than the relative growth of the succeeding 4 days. The onset of the slower growth is correlated in time with yolk-sac absorption.

An area which is bounded by line 80 on the north, line 110 on the south, stations 90 on the west, and the coast of California and Baja California on the east has been shown to contain almost all the month-old larvae.

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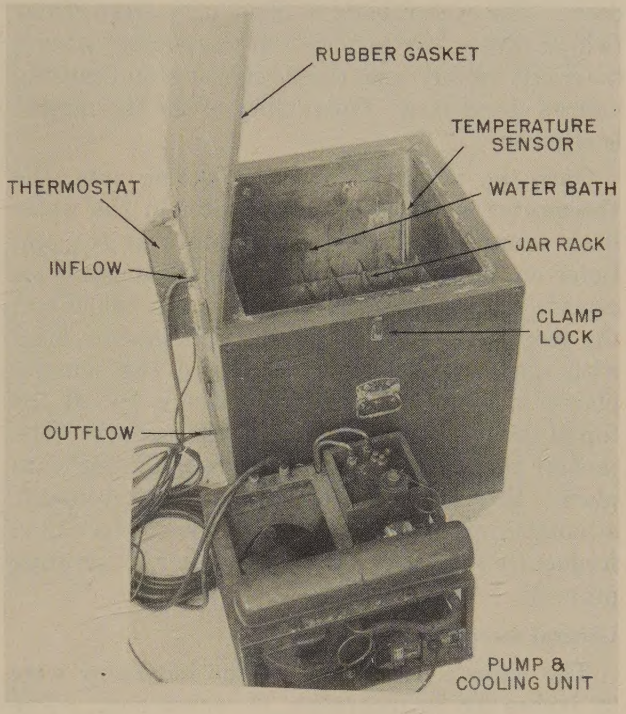
APPENDIX

A. FISH EGG INCUBATOR

scription

When estimating the total abundance of pelagic
n eggs it is necessary to know the rate of develop-
nt. Since this parameter varies with tempera-
re it has been customary in the past to compute
egression of log hours of development against
nperature in tenths of a degree centigrade. This
irect method, while very accurate, is extremely
orious and time consuming. A more direct
thod was desired, and with this need in mind,
incubator was designed for use at sea.

Since most of the biological material is taken
ll offshore, and since hatching times are rela-
ely short, it is necessary to work at sea. Some
the many technical problems that are peculiar
sea work and their solutions are described here.
The pitch and roll of ships cause delicate equip-
nt to be damaged quite easily, and the need for
rdy construction is readily apparent. Instru-
nts such as this one should be portable, since
y have a limited use and cannot be left aboard
earch vessels indefinitely. A compromise be-
en sturdy construction and portability of an
incubator was effected by resorting to a double-
construction, using marine plywood. The
nperature-sensing and temperature-control de-
es were of a mechanical nature. A heavy duty, stainless steel sensing element enclosing a mercury column was employed. The mercury column activated a mechanical linkage in the thermostat, which in turn opened and closed an electrical switch. The circulating pump and cooling device were remote from the incubator itself, but connected by garden hoses (appendix fig. 1). The



APPENDIX FIGURE 1.—Fish egg incubator.

separation of units contributed to the portability of the instrument.

Corrosion from the salt air which attacks most metals was controlled by using a synthetic resin paint on all exposed parts of the incubator. Other structures were concealed in corrosion resistant housings.

Temperature control (± 0.2° C. of selected temperature) was obtained by using the main water mass in the water bath as a heat reservoir. As the water mass warmed, the change in temperature was recorded by the sensing element and the water routed through the cooling mechanism. It was believed that temperature changes in the incubation chambers were small, because the main water mass was so large, by comparison, that a large amount of heat would have to be transferred before any appreciable temperature change in the incubation chambers would occur.

The eggs were incubated in pint or quart mason fruit jars. The pint jars had glass tops held in place by a spring clamp; the quart jars were wide-mouthed and equipped with plastic lids.

Procedure for use

While the vessel is still at the dock, the incubator and cooling mechanism are secured to the deck. The water bath is filled with fresh water (which causes less corrosion in the cooling system than salt water) and the circulating and cooling motors are started. Operability of the thermostat is checked.

Once the vessel is in the collecting area, the thermostat is set so that the water in the water bath assumes the same temperature as the sea. Later on, at the time the biological sample is received, a bathythermograph reading is taken and the thermostat adjusted. The fruit jars are filled with sea water from the area and the samples placed in them. A small air space is left at the top of the jars to aid aeration of the sample. The jars are then placed in the jar rack and locked into place. From then on the operation is automatic, although temperature readings should be taken frequently to assure that the incubator is operating properly.

General specifications

The outside dimensions of the incubator were 32 inches by 32 inches by 35 inches deep. The inside dimensions, the perimeter of the water bath, were 26 inches by 26 inches by 26 inches. Both the inside and outside boxes were made of ⅝-inch marine plywood fastened together with brass screws. The space between the boxes was filled with an insulating material. The inside box was lined with copper sheeting that had been soldered at the joints and was therefore watertight. The jar rack also was made of copper. The individual chambers of the bottle rack were 4 inches square and accommodated either pint or quart wide-mouthed jars.

The copper lining was pierced by three holes: one for inflowing water, one for outflowing water, and one for the temperature-sensing element.

The lid was fastened by two heavy metal strap hinges and three clamp locks. A sponge-rubber gasket prevented leakage.

The water in the water bath was circulated by Jabsco pump and cooled by a Temprite cool The temperature control was maintained by Partlow thermostat. Two ¼-inch plastic gard hoses with brass fittings connected the pump a cooler with the water bath. All exposed surfac were painted with green plastic paint.

B. STAGING SCHEME OF JACK MACKEREL EGGS

Stage I.—Unfertilized eggs or fertilized eggs b fore cell division.

Stage II.—Begins when the first cell becom visible on the yoke and ends at the completio of blastodisk formation (at about the 256-c stage).

Stage III.—Starts at the completion of blastodis formation and terminates when the germ ri has migrated to its greatest diameter (half-wa up the egg).

Stage IV.—Begins as the germ ring moves u ward over the greatest diameter and ends whe the germ ring lies over the oil globule, prior blastopore closure.

Stage V.—Begins at blastopore closure and te minates when the tail bud starts to separat from the yolk.

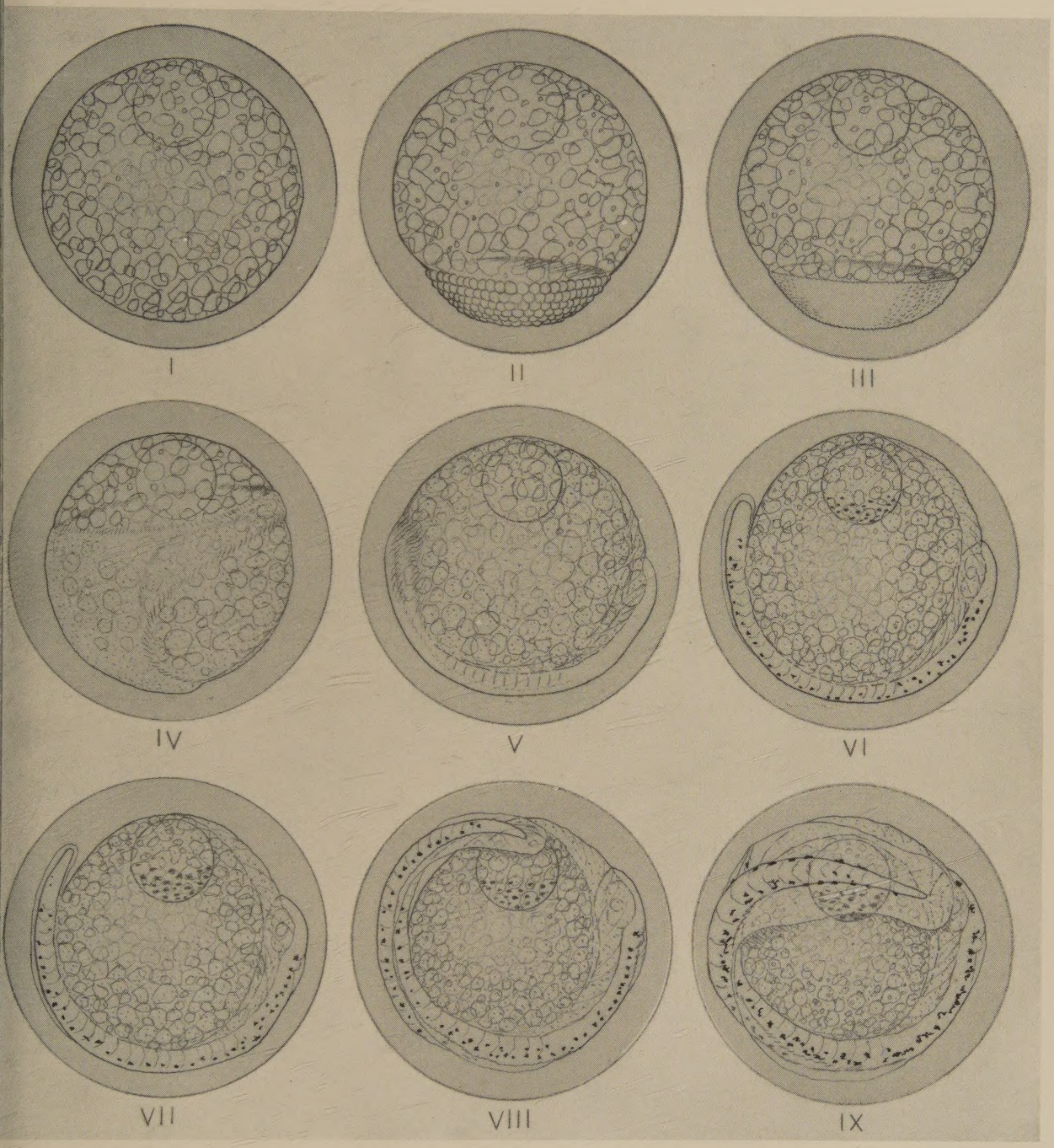
Stage VI.—Begins when the tail bud becomes fre of the yolk and ends when the caudal one-eight of the body is free of the yolk.

Stage VII.—Begins when the caudal one-eight of the body is free of the yolk and ends whe the caudal one-quarter of the body is free of th yolk. A finfold is visible.

Stage VIII.—Begins when the caudal one-quarte of the body is free of the yolk and the tip of th tail approaches the chin. The tail portion o the embryo begins to rotate out of the em bryonic plane and the finfold is moderatel wide.

Stage IX.—This stage is characterized by the ti of the tail laterally approaching the head. Th oil globule comes to lie in the anteroventra portion of the yolk sac. The finfold is wide an fully formed. This stage terminates when th embryo hatches.

Disintegrate.—Includes all jack mackerel egg whose internal structure is such that staging i impossible.



APPENDIX FIGURE 2.—Stages of jack mackerel egg development.

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